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Laboratory Experiments For 3rd Year Electrical Engineering Students (Power and Machines Section)

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(I)

Electrical Machines Experiments

(1)
Construction, Starting and Reversing of 3-phase Induction Motors

Objective:

a. To study the construction of a 3-phase induction motor
b. To study the different starting methods of 3-phase induction motors
c. To study how to reverse the direction of rotation in a 3-phase induction motor.

Theory:
Construction:
The induction motor essentially consists of two parts:
- Stator
- Rotor.

The supply is connected to the stator and the rotor received power by induction caused by the stator rotating flux, hence the motor obtains its name –induction motor.
The stator consists of a cylindrical laminated & slotted core placed in a frame of rolled or cast steel. The frame provides mechanical protection and carries the terminal box and the end covers with bearings. In the slots a 3-phase winding of insulated copper wire is distributed which can be wound for 2,4,6 etc. poles.
The *rotor* consists of a laminated and slotted core tightly pressed on the shaft.
There are two general types of rotors:
- The squirrel-cage rotor,
- The wound (or slip ring) rotor.

In *the squirrel-cage rotor*, the rotor winding consists of single copper or aluminum bars placed in the slots and short-circuited by end-rings on both sides of the rotor.
In the *wound rotor*, an insulated 3-phase winding similar to the stator winding and for the same number of poles is placed in the rotor slots. The ends of the star or delta connected rotor winding are brought to three slip rings on the shaft so that connection can be made to it for starting or speed control.

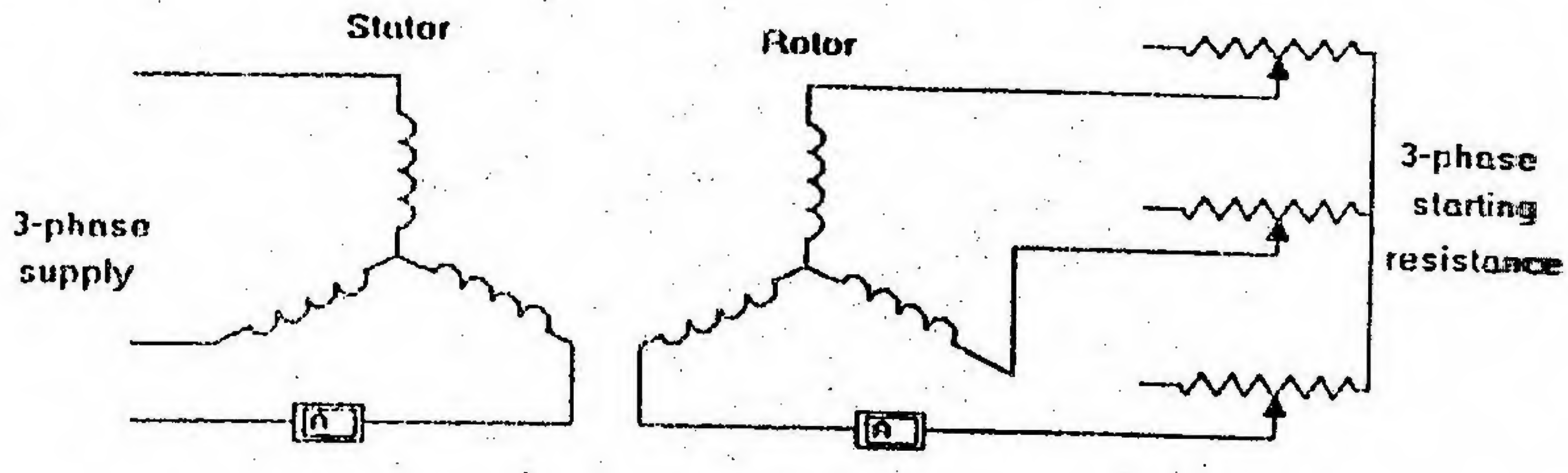


Fig. 1

3. For direct-on -line starting , connect the cage motor as shown in Fig. 2.
4. For star-delta starting , connect the cage motor to the terminals of the star/delta switch, Fig. 3.
5. For autotransformer starting, connect the cage motor as shown in Fig. 4. Take care at starting that the "Run" switch is open and that it is not closed before the "Start" switch is opened.
6. In each case observe the starting currents by quickly reading the maximum indication of the ammeters in the stator circuit.
7. Reverse the direction of rotation of the motor by reversing of two phases at the terminal box. The reversal has to be made when the motor is stopped and the supply switched off.

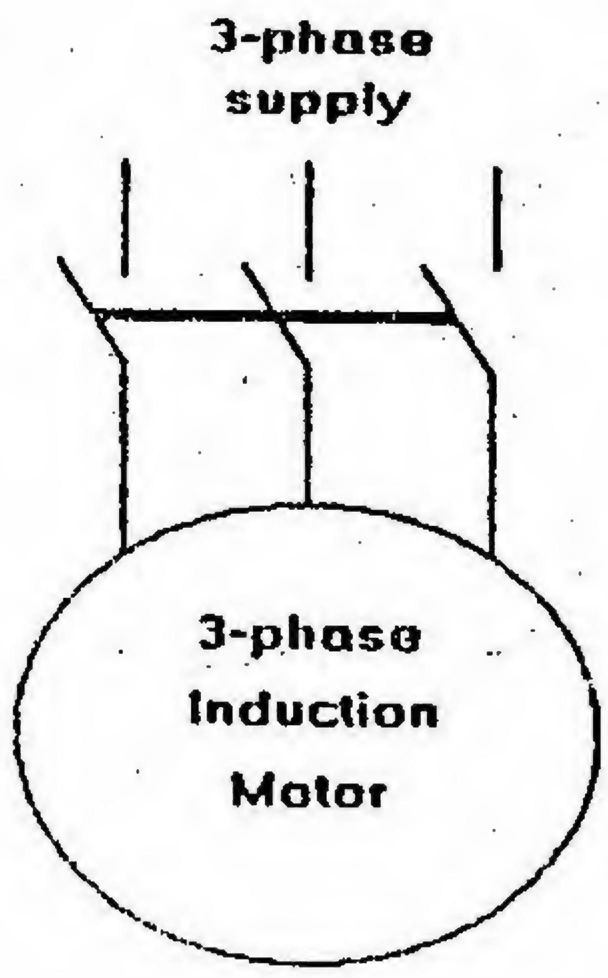


Fig. 2

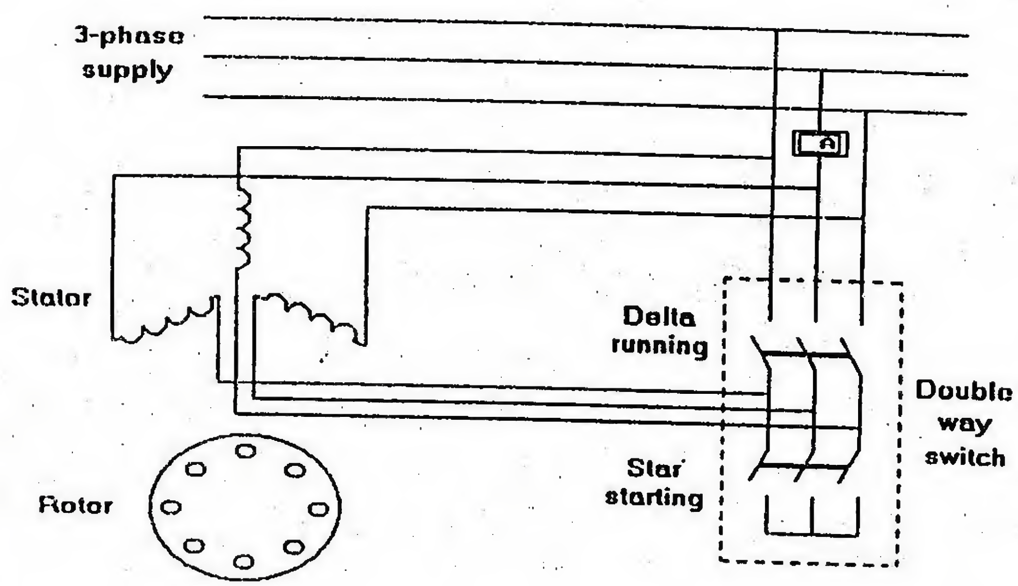


Fig. 3

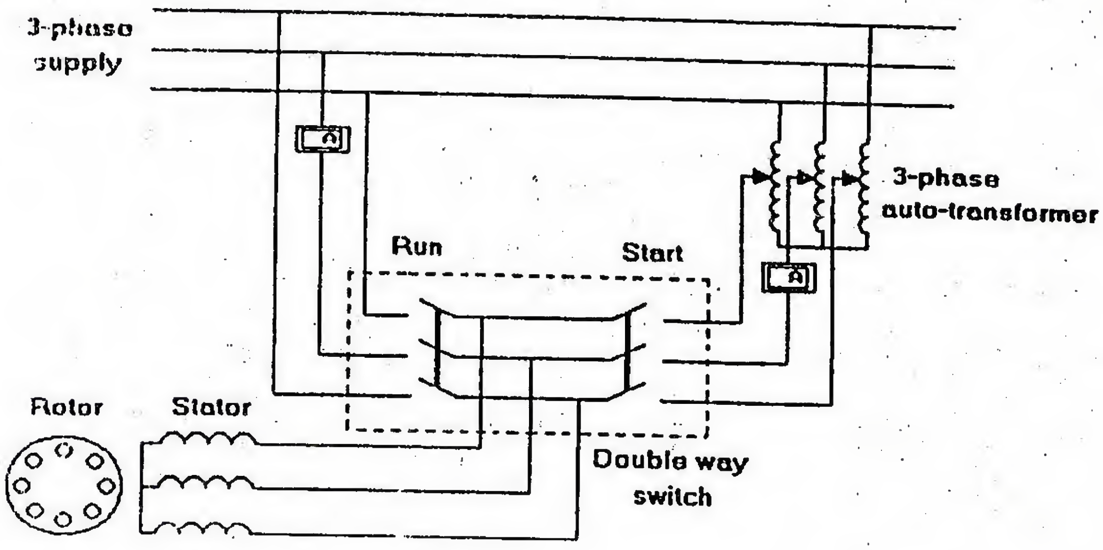


Fig. 4

Report:

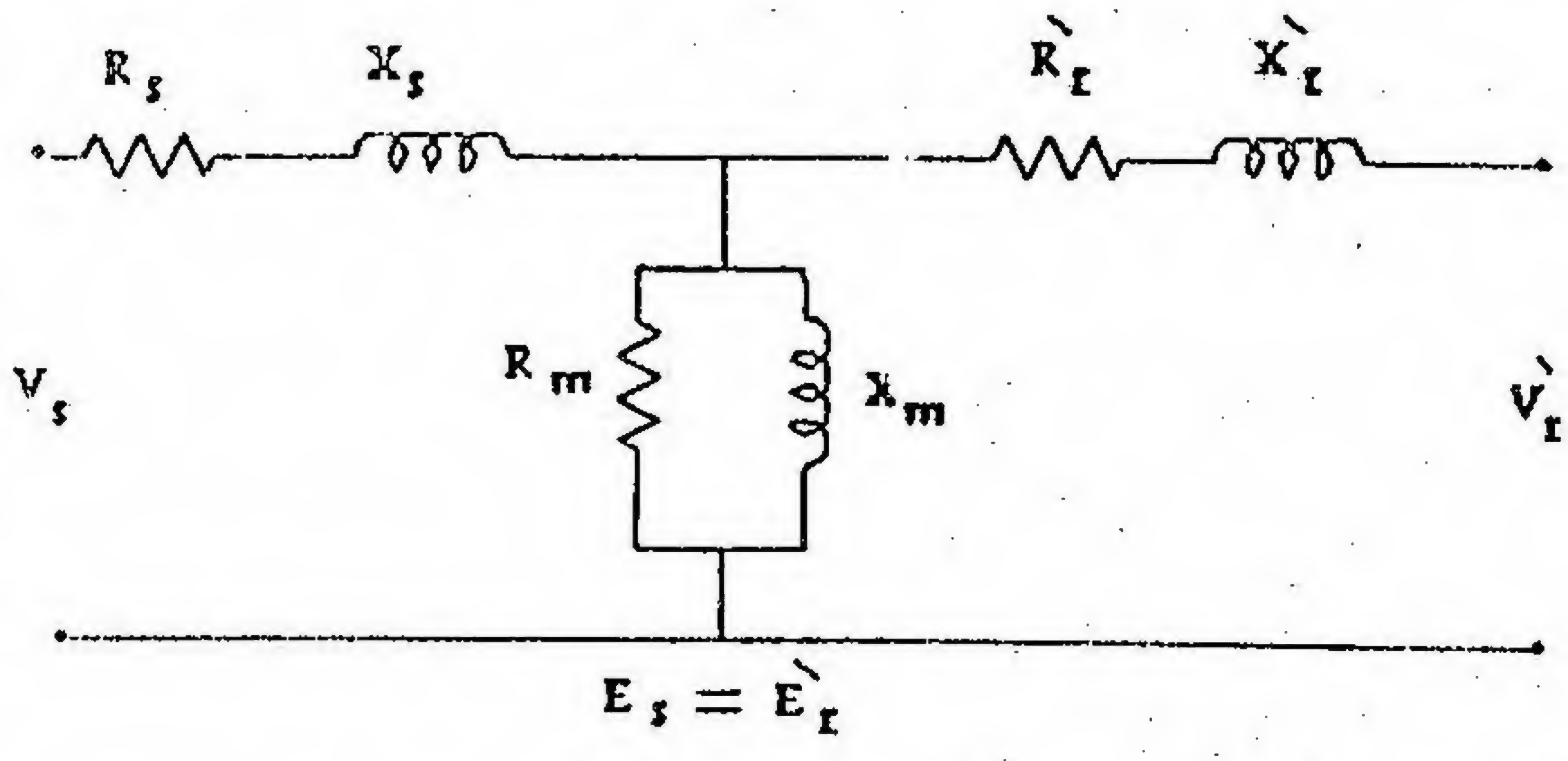
1. Explain the difference between a slip ring and a squirrel -cage motor.
2. Discuss the merits & demerits of the various starting methods.

(2)
Performance characteristics of 3-phase Induction Motor

Theorotical Notes on Experiment:

1) Standstill Conditions:

As long as the rotor is stationary, the machine behaves as a transformer. The constants of the equivalent circuit may be obtained, as in the case of the transformer, by direct measurements at standstill.
With one side open, say rotor, we have:
$V_s = V'_r + I_s (R_s + jX_s)$



From which X_s and X_m may be calculated. For practical purposes, these may be calculated as:
$X_s = V_s - V'_r/I_s$ & $X_m = V'_r/I_s$
The turns ratio N_s/N_r, which is necessary to calculate V'_r from the measured value of V_r may be obtained from the results of the same test, since $N_s/N_r = (V_s/V_r)$ when $I_s = 0$.
The function $V_s/V_r = f(I_s)$ gives, therefore, when extrapolated till the vertical axis, the approximate value of N_s/N_r.
It is important to calculate X_m for rated voltage, since it varies considerably with the degree of saturation.
With the rotor short-circuited at stand-still, the small magnetizing current may be neglected, which leads to:

$$V_s = I_s[R_s + R'_r + j(X_s+X'_r)]$$

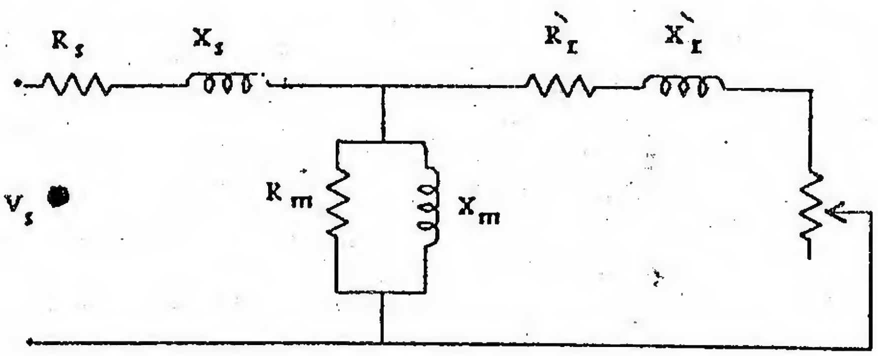
From which the sums $R_s+R'_r$ and $X_s + X'_L$ may be calculated the power dessipation as heat in the rotor during this test, the power dessipation as heat in the rotor during this test, which is obviously transferred to by induction

from the rotating field, necessitates the prosence of a certain torque is given by:

$$M = 3 I_r^2 R_r / N_s = \frac{0.975 P_g}{N_s} \text{ kg.M.}$$

This gives the electromagnetic torque acting on the rotor at standstill. The values of resistance and loakage reactance of stator and rotor for the equivalent circuit should be taken from the results of the short-circuit test. The seperation of stator and rotor constants follows for loakage reactances tests, and resistances in the ratio of the values measured by D.C.

2) **Running Condition**



For the analytical treatment of the induction machine, it can be locked-upon as a transformer loaded with a resistive load of $R_r(1\text{-}S)/S$. with the machine running at no-load the slip is practically zero and the "external" resistance of the equivalent circuit is very large. The power drawn by the machine under these conditions is mainly due to the iron losses in the stator, which are approximately proportional to the square of the applied voltage, and the friction and winding losses, which are practically constant. The function $W_o = f(V_s)$ gives, therefore, when extrapolated till the vertical axis, the magnitude of the friction and winding losses. For accurate results the values of W_o should be corrected for the copper loss in the stator. If the rotor is blocked and an external resistance R/phase is inserted in the rotor circuit, the conditions of the machine correspond to the actual running conditions at a slip given by;

$$R = R_r(1\text{-}S)/S \text{ or } S = R_r / R + R_r$$

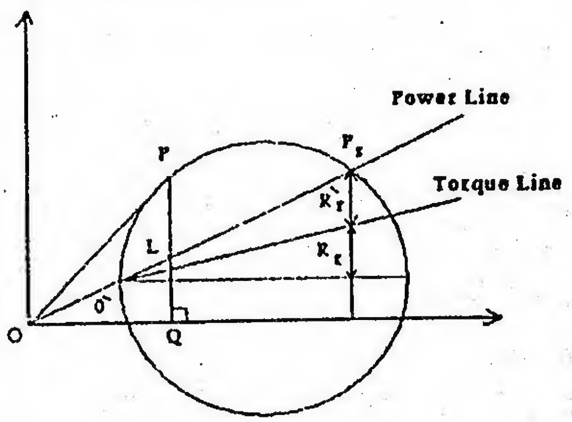
All quantities measured under such conditions at standstill should, therefore, be the same as those of actual running with the above slip. However, due to the fact that he rotor frequency, effective resistance and iron losses are different from actual running conditions, and also due to

the effects of the slots of stator and rotor and to some other secondary effects, the importance of such a test is confined mainly to the study of the starting characteristics and an illustration of the torque charactaristic.

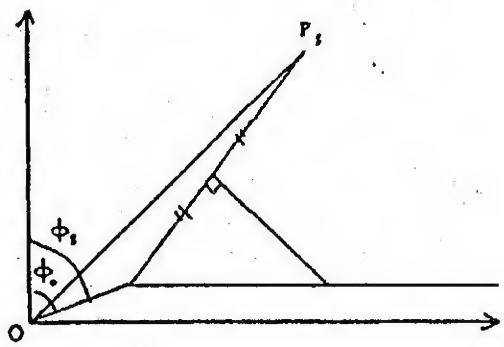
3) The circle diagram

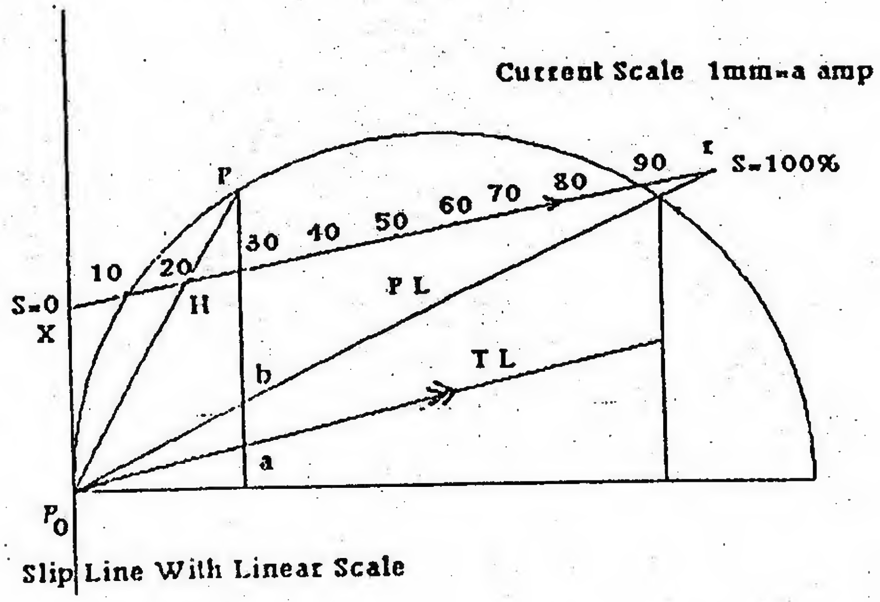
The prodetermination of the performance characteristics of the machine is carried out graphically by constructing the current circle diagram from the results of the no-load and short-circuit tests. The construction of the circle diagram and the method of deduction of all quantities is illustrated in the following figures.

Power and Torque Linear .



Determination of Center .





No-load Current = a.OP amp.
Stator Current = a.OP amp.
Rotor Current = a.P amp.
Electrical Input = $3.V_s$.a. PQ watt
Air-gap power = $3.V_s$.a. PF watt
Mechanical Output = $3.V_s$.a. PL watt
Brake Torque = $3.V_s$.a. PF.0.975/ns kg.m
Efficiency = PL/PQ

Slip line with linear scale:

References:

1) A.F. Puchstein & T.C. Lioyd : Alternating Current Machines.
2) M.G. Say & E.N. Pink : The Performance & Design of A.C. Machines.
3) A.S. Langdorf : Theory of Alternating Current Machinery.

Polyphase Induction Machine
Experiments

1) Prelininary:

Inspect the machine under test and take complete particulars and data given on its rating shield. Notice the method of starting and examine the construction of the stator and the brush-lifting, short-circuiting device, the connection of the machine to the supply and protection relays used.

2) No-load test as transformer

a) With the rotor circuit open, apply a variable voltage to the stator, Measure the input currents, voltages and powers and secondary voltages for different values of stator voltage between 130% & 30% of rated value. Plot curves of stator voltage and power to a base of stator current. Plot to the same base the voltage ratio and extrapolate to obtain the effective turns-ratio. Calculate for the rated voltage the value of the magnetizing reactance and the stator leakage reactance per phase.

b) Repeat the above test with the voltage applied to rotor and stator open. Compare the two sets of curves. Calculate for the same value of air-gap flux the magnetizing reactance and rotor leakage reactance per phase.

3) Stand-Still test:

a) Apply a claming device or a brake to the rotor with provision to measure the torque developed. With the rotor short-circuited, apply a reduced voltage to the stator and adjust its value to get about 150% of rated current. Measure stator voltage, current, power and the torque. Repeat for lower values of stator voltage. Plot curves of stator current, power and starting torque to a base of stator voltage. Deduce the value corresponding to rated voltage by extrupolation or calculation. Calculate the value of the total leakage reactance at rated current and discuss the reasons, why this differs somewhat from the sum of the individual values obtained in test (2)

b) With the same arrangement as above, adjust the stator voltage to a value, corresponding to about 150% of rated current, rotor being short-circuited. Keeping this voltage constant, insert the starting resistance in the rotor circuit in steps and measure at each step the torque developed and the stator currents and power. From the results obtained, deduce the torque speed curve of the running motor at rated voltage.

4) No-load test as motor:

Start the motor and let it run at no-load. Measure the input voltage, current, power and slip for different values of the stator voltage between 10% and 30% of rated value.

5) Load test:

Couple the motor to the D.C. machine and let it run at normal voltage. Load the motor to about 25% overload and measure input power, currents, slip and output power. Reduce the load in steps and take the same measurements.

6) Resistance measurements and calibration of load dynamo:

With the windings still warm measure the stator and rotor resistance the steps of the starting resistance. If the load dynamo is to be calibrated, measure its armature resistance and its no-load losses.

DEDUCTIONS:

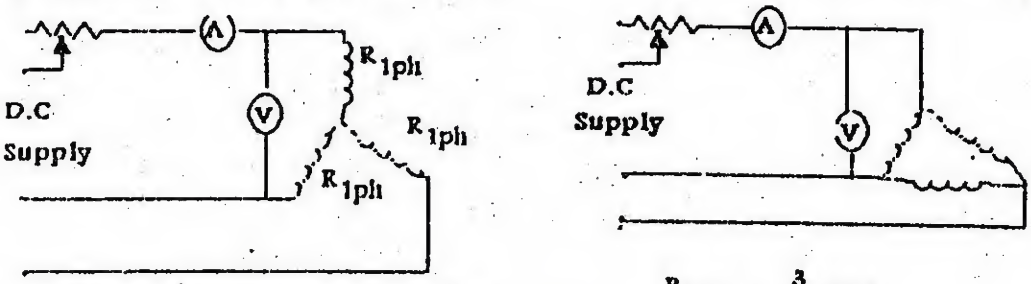
a) Calculate the constants of the equivalent circuit of the machine.

b) Draw the circle diagram of the machine at rated voltage and deduce from it the performance curves for the normal operating range as motor. Indicate on these curves the experiments results obtained in test (5).

c) Deduce from the circle diagram the torque-speed curve of the motor and compare with the curve obtained in test (4-b)

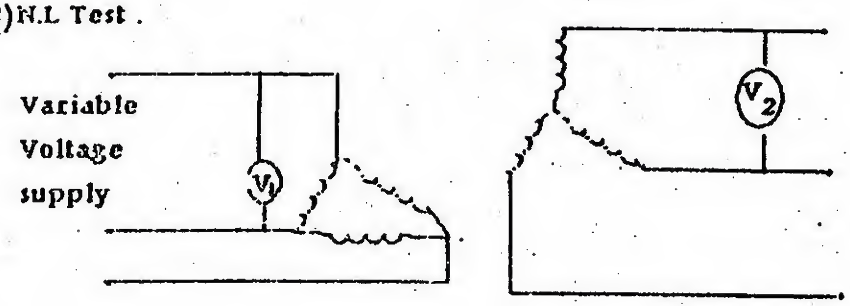
d) Determine from the circle diagram the break-down torque maximum power input, maximum power-factor and the corresponding values of slip.

1)Measurements of Stator Resistance.-

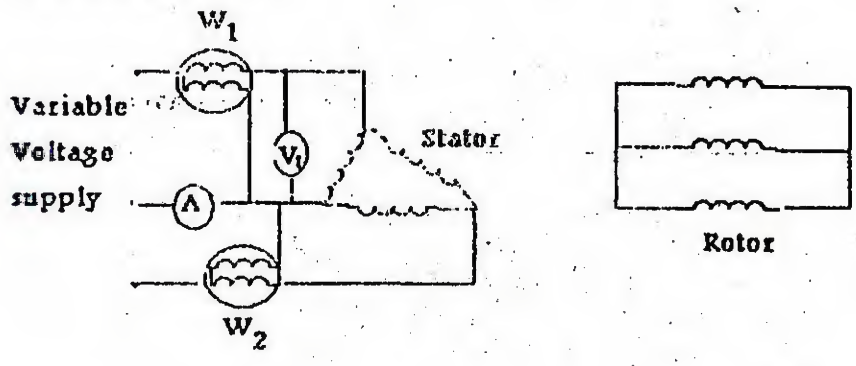


$R_{1ph} = \frac{1}{2}$ (V/I) $R_{1ph} = \frac{3}{2}$ (V/I)

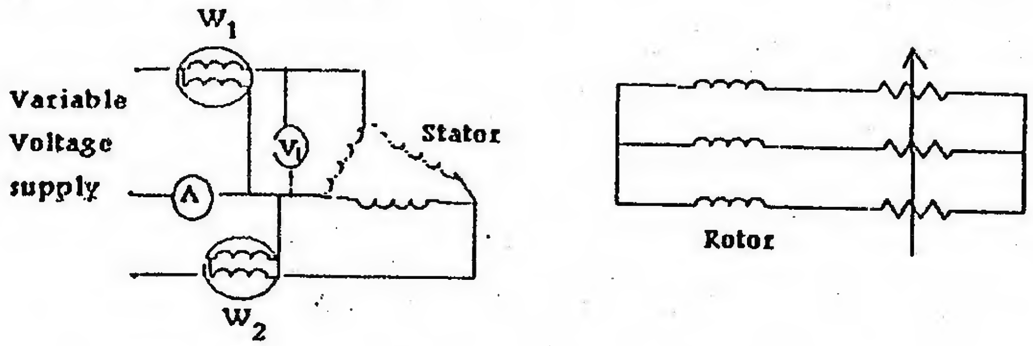
2)N.L Test .



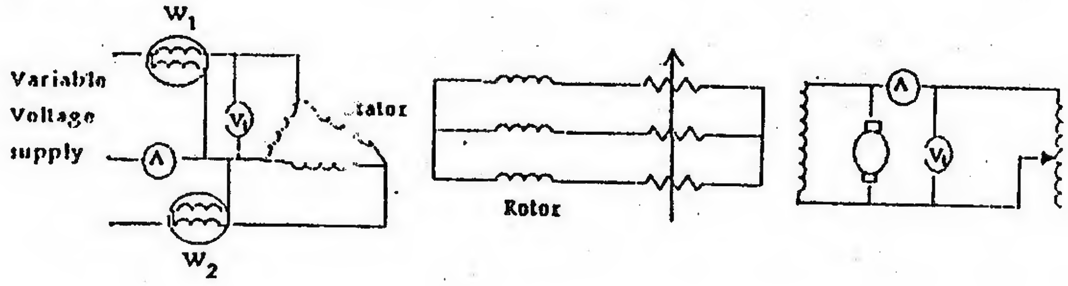
3) Stand Still Test .



4) N.L Test as atransformer



5) Load Test :-

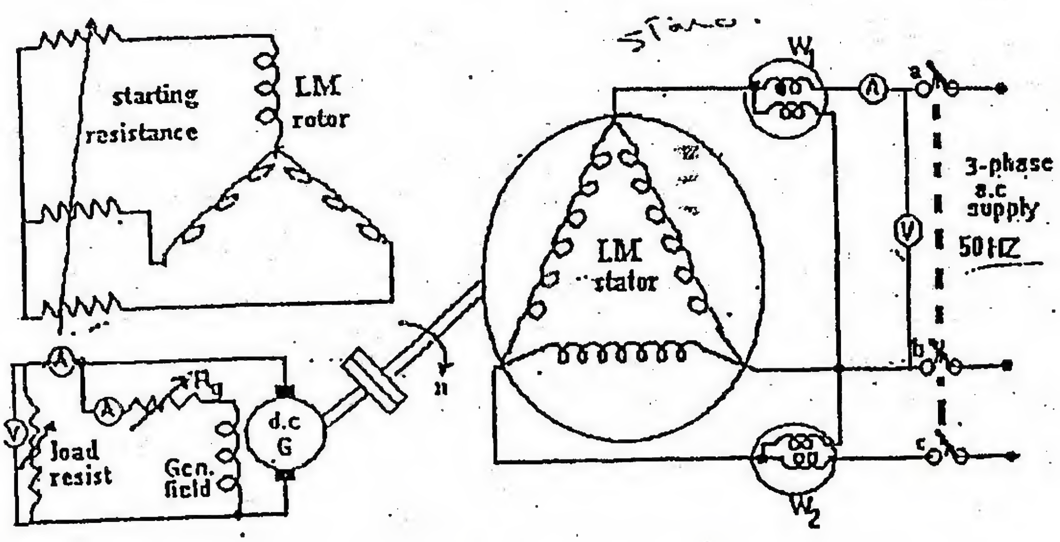


(3)

(I) Measurement of T-n Characteristics of a 3-phase Slip-Ring Induction Motor with Various Rotor Starter Resistors

Object:

To plot the torque-speed characteristics of a 3-phase slip ring induction motor with variable rotor resistance.



Connection Diagram

Experiment:

(1) Connect the 3-phase induction motor circuit as shown in figure.

(2) Increase the load on the induction motor from its no-load value to its maximum value by increasing the load on the directly coupled d.c generator, for different values of induction motor rotor starting resistance.

(3) Take simultaneous readings for speed n, P_{input}, stator current I_1 and input supply voltage V_1. $P_{inp} = W_1 \pm W_2$

(4) Calculate the power output of the induction motor, torque output for different values of speed.

$P_{out} = P_{input}$ – no load losses – $3 * I_1^2 * R_{eq1}$ [w]

Where

Induction motor no load losses (mech. + stator iron losses) may be taken approximately = ½ power input to the motor generator set at no load.

$R_{eq1} = r_1 + r_2' =$ equivalent motor resistance [ohm]

R_{eq1} may be determined from locked rotor test on the 3-phase induction motor.

The torque output of I.M. $T = P_o / (2 * \pi * n/60)$ [N]

(5) Plot curves showing how the torque output T and input current I_1 varies as function of speed n for different values of rotor starter resistance.

(6) If the load torque is assumed to be constant draw a relation between motor speed n and the value of rotor starter resistor.

Discussions:

(1) Comment on the shape of the obtained results.

(2) How are the starting torque and starting current influenced by rotor starter resistor?

(3) What advantages do rotor starter offer with respect to the starting behavior?

(4) Explain why inductive reactors are not suitable for starting a 3-phase slip-ring induction motor.

(II) Measurement of T-n and I_1 – n Characteristics of a 3-phase Squirrel-Cage for Star and Delta Connection Objectives

Object:

To obtain and plot the T-n and I_1-n characteristics for squirrel-cage I.M with Y/Δ starter, with the switch in the Y and in the Δ - positions.

Experiment:

(1) Repeat the above procedure for the 3-phase given squirrel-cage induction motor with the Y/Δ switch in the Y and then in the Δ - positions.

(2) Plot curves showing the variation of the T-n and I_1–n characteristics for the Y and Δ -positions.

Discussions:

(1) Comment on the shape of the characteristics obtained for both positions.

(2) What disadvantages have the Y/Δ starter, when used for starting of 3-phase squirrel-cage motors?

(3) What torque is produced by the motor at no-load speed?

(4)
Separation of Losses of an Induction Motor

Objective:
To separate the various losses occurring in an induction motor.

Theory:
The losses occurring in an induction motor include the following:
P_b = brush friction loss
P_e = eddy current loss in iron
P_f= mechanical losses in windage and bearing friction
P_h = hysterisis loss
P_p =pulsation loss
P_{cu}= copper loss
At standstill the rotor core loss is $P_{e2}+ P_{h2}$, when the rotor is open-circuited. At a slip s, this loss becomes $s^2 P_{e2}+sP_{h2}$. The suffixes 1 and 2 refer to stator and rotor respectively.
The pulsation loss is a high-frequency tooth loss in stator & rotor, produced by variations of gap reluctance as the tooth tips pass each other. The friction loss can be separated by the no-load test.

Procedure:
The following procedure separates all losses for the slip-ring motor:

No-load Test
1. Measure the stator input power at normal voltage and at rest rotor open circuit, Fig. 1. This power is the iron losses $P_1= P_{e1}+ P_{h1}+P_{e2}+ P_{h2}$.
2. Measure the stator input power at normal voltage and frequency with the rotor short-circuited and running on no-load. The stator input is $P_2= P_{e1}+ P_{h1}+P_p+ P_f + P_b$.
   The rotor eddy current loss is small since it is proportional to s. P_{h2} is also supplied by the stator, but practically the whole of it is returned as a driving torque, partly providing for $P_f + P_b$.
3. With machine running as in (2), the rotor circuit is suddenly opened and the stator input measured. The stator input power falls to
   $P_3= P_{e1}+ P_{h1}+ P_{h2}$.

Transformation Ratio test
4. Apply a voltage to the rotor such that the stator voltage is $(V_1+v_1)/2$ on open circuit, and the mutual flux is normal where V_1 is the normal

stator applied voltage and v_1 is the measured stator voltage when the normal voltage V_2 is applied to the rotor.

Measure the rotor input power when running on no-load with the stator short-circuited. This corresponds to the condition of (2), except that the functions of the rotor and stator are reversed. The rotor power input is $P_4 = P_{c2} + P_{h2} + P_p + P_f + P_b$.

5. With the machine running as in (4), the stator is suddenly open-circuited and the rotor power input falls to $P_5 = P_{c2} + P_{h2} + P_{h1}$. The mechanical losses P_6 ($P_6 = p_f + p_b$) are evaluated by the no-load test

Locked Rotor Test

6. Measure the stator input power at reduced voltage and full-load stator current, P_{sc}, with the rotor short-circuited and locked. This test gives the stator and rotor copper losses of the machine. Take readings for the stator current ,I_{sc}, stator applied voltage, V_{sc} and the stator resistance per phase, Fig. 2.

Calculations:

From no-load test

$P_{c1} = P_1 - P_5$

$P_{c2} = P_1 - P_3$

$P_{h1} = P_5 + (P_2 - P_4 - P_1)/2$

$P_{h2} = P_3 + (P_4 - P_2 - P_1)/2$

$P_p = (P_2 + P_4 - P_1)/2 - P_6$

$P_6 = P_f + P_b$

Assuming $P_f = P_b = P_6/2$

From locked rotor test

Corresponding Values for normal stator voltage V will be:

$I = V\, I_{sc} / V_{sc}$

$P = P_1 \pm P_2 = P_{sc} (V/V_{sc})^2$

$P_{cu1} = 3(I)^2 R$

$P_{cu2} = P - 3(I)^2 R$

Discussion:

1. The brush friction loss cannot be measured if there is no internal short-circuiting device. In that case, assume $P_b = 0$.
2. The rotor eddy current loss is very small, because it is proportional to the rotor slip and this is very small.
3. To get accurate results, the voltage should be maintained constant.

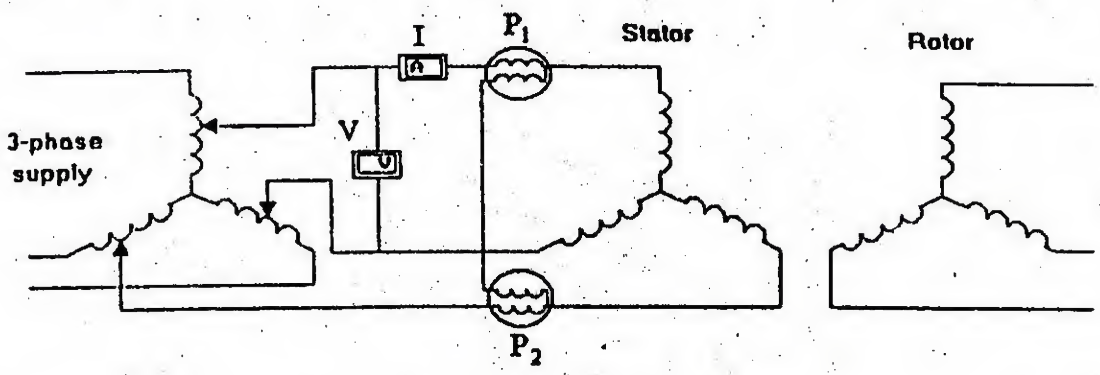


Fig. 1: Induction motor at standstill

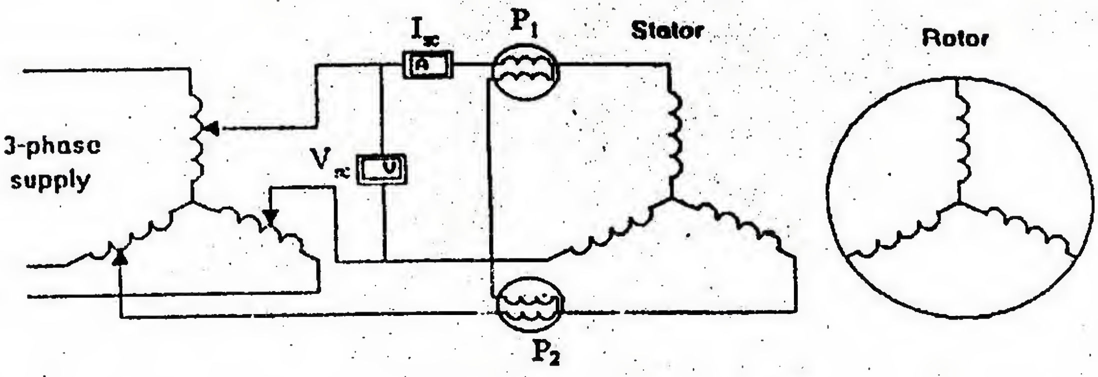


Fig. 2: Locked rotor test

(5)
External Characteristics of Synchronous Generator

Object:

To determine the external characteristic for the synchronous generator in laboratory, for resistive, inductive and capacitive loads.

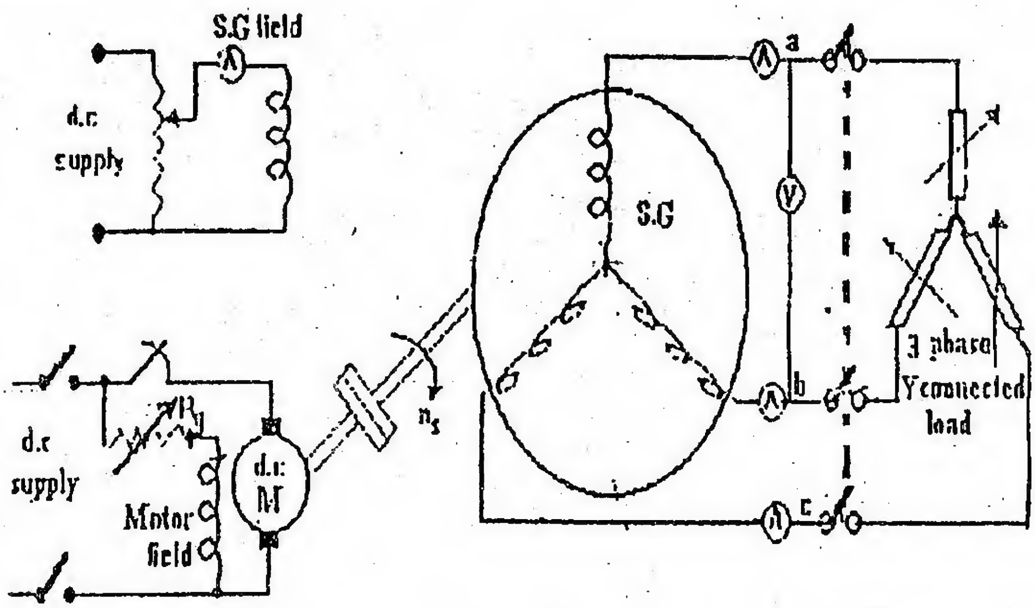
Experiment:

(1) Take complete particulars of the synchronous generator and the driving motor under test.

(2) The synchronous generator is connected as shown in figure with its terminals a,b, and c connected to pure resistive, inductive and capcitive loads respectively.

(3) The synchronous generator is driven by the d.c. directly coupled motor at its synchronous speed.

(4) The field current is adjusted to value, which gives the name-plate terminal voltage at no-load. This field current value will be kept constant during the experiment.



(5) The load current is varied in steps from no-load value to 1.25 of the rated value, by varying the load resistance.

(6) Take readings for the load current and load voltage.

(7) Draw the synchronous generator external characteristic as a relation between load current and load voltage.

(8) Repeat the above for pure inductive and capacitive loads respectively.

Discussions:

(1) Comment on the shape of the obtained external characteristics.

(2) With the aid of vector diagrams, explain briefly the performance of synchronous generator under resistive, inductive and capacitive loads.

(3) Comment on the value of the voltage regulation in each case.

(6)
Voltage Regulation of a Synchronous Generator

Objective:

To determine the voltage regulation of an alternator by the synchronous impedance method and zero power factor method.

Theory:

Voltage regulation of an alternator is defined as the rise in terminal voltage of the machine expressed as a fraction percentage of the initial voltage when specified load at a particular power factor is reduced to zero, the speed and excitation remaining unchanged.

The experiment involves the determination of the following characteristics and parameters:

1. The open -circuit characteristic (the O.C.C)
2. The short-circuit characteristic (the S.C.C)
3. The effective resistance of the armature winding.

The O.C.C is a plot of the armature terminal voltage as a function of field current while the S.C.C. is a plot of the armature current as a function of field current with a symmetrical three phase short-circuit applied across the armature terminals with the machine running at rated speed.

At any value of field current, if E is the open circuit voltage and Isc is the short circuit current then for this value of excitation

$$Zs = E/I_{sc}$$

At higher values of field current, saturation increases and the synchronous impedance decreases. The value of Zs calculated for the unsaturated region of the O.C.C is called the unsaturated value of the synchronous impedance.

If Ra is the effective resistance of the armature per phase, the synchronous reactance Xs is given by

$$Xs = \text{sqrt}\,(Z_s^2 - Ra^2)$$

If V is the magnitude of the rated voltage of the machine and the regulation is to be calculated for a load current I at a power factor angle ϕ, then the corresponding magnitude of the open circuit voltage E is

$$E = V + IZs$$

Here bold letters indicate complex numbers.

$$\text{Regulation} = (E-V)/V$$

Procedure:

1. Open circuit characteristic

Connect the alternator as shown in FIG.1. The prime mover in this experiment is a D.C. shunt motor, connected with resistances in its armature and field circuits so as to enable the speed of the set to be controlled. Run the set at the rated speed of the alternator, and for each setting of the field current, record the alternator terminal voltage and the field current. Note that there is no load on the alternator. Record readings till open circuit voltage reaches 120% of the rated voltage of the machine.

2. Short circuit characteristic

(FIG.2) Connect as in FIG.1, but short-circuit the armature terminals through an ammeter. The current range of the instrument should be about 25-50 % more than the full load current of the alternator. Starting with zero field current, increase the field current gradually till rated current flows in the armature. The speed of the set in this test also is tom be maintained at the rated speed of the alternator. Record the field and armature currents.

3. Measure the D.C. resistance of the armature circuit of the alternator. The effective a.c resistance may be taken to be 1.2 times the D.C. resistance.

3- Zero-Power Factor Test:

1. Drive the alternator at its synchronous speed Fig.3 and connect its terminals through the ammeters across the balanced 3-phase pure inductance. These variable inductances are of the air-cored type to ensure linear variation.
2. Starting from the lowest value of the inductance, vary its value in steps keeping the line current constant at 25 amp. by means of the field current regulating potentiometer.
3. Record the field current and the terminal voltage at each step.
4. The zero P>F. characteristic yields the relationship $V = f(I_f)$ at constant armature current is plotted.

Report:

1. Plot on the same graph sheet, the O.C.C (open circuit terminal voltage per phase versus the field current), the short-circuit characteristic (short-circuit armature current versus the field current) and the zero power factor character.

2. Calculate the unsaturated value of the synchronous impedance, and the value corresponding to rated current at short circuit. Also calculate the corresponding values of the synchronous reactance.
3. Calculate regulation of the alternator under the following conditions:
- Full load current at unity power factor
- Full load current at 0.8 power factor lagging.
- Full-load current at 0.8 power factor leading.

Use the synchronous impedance and the general methods.

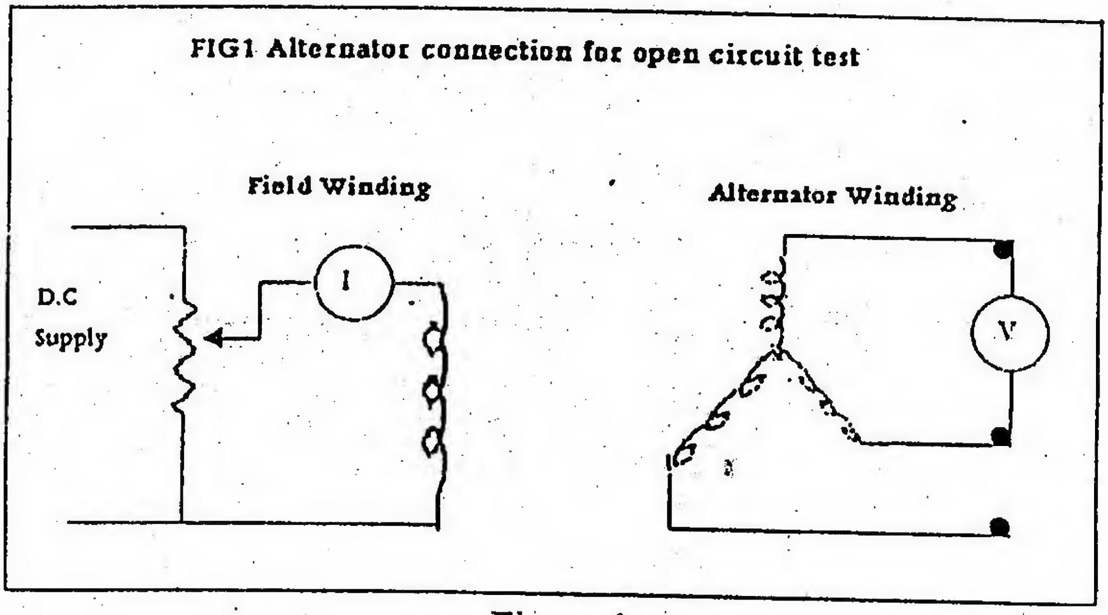


Figure 1

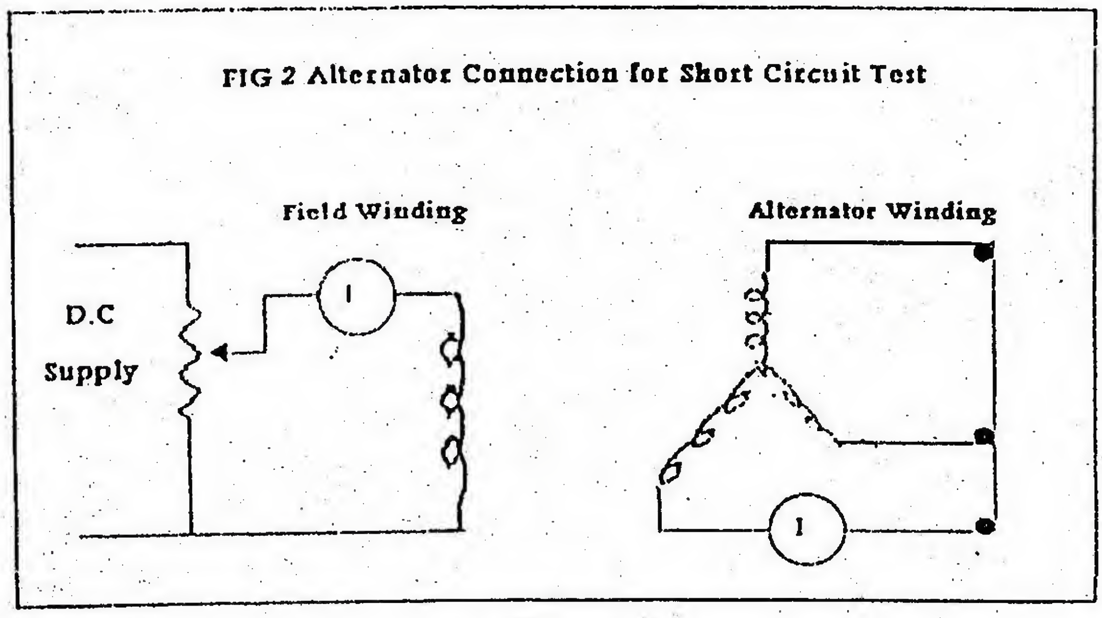


Figure 2

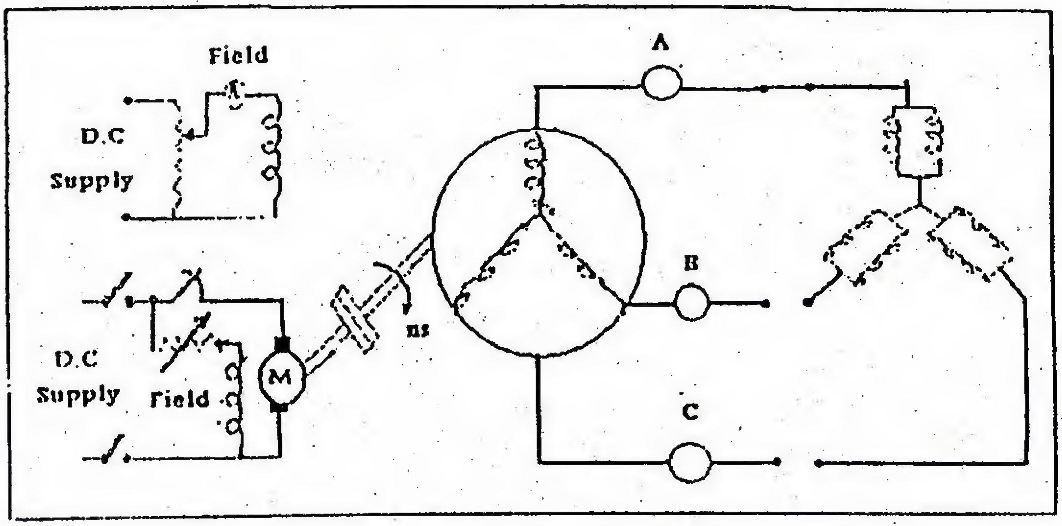


Figure 3

(7)
Synchronous Generator Characteristics

Objective:
To determine the compounding curve & the volt-ampere curve of a synchronous generator

Theory:
The synchronous machine is one in which a.c flows in the armature winding and D.C. is applied to the field winding. The armature winding is usually on the stator.
Synchronous generators are usually rated in terms of the maximum kVA loads at the specified voltage and power factor, which they carry continuously without overheating.
The main steady-state operating characteristics are:
I. Field current versus armature current
II. Terminal voltage versus armature current.
Consider a synchronous generator delivering power at constant frequency to a unity power factor (i.e. resistive) load. The curve showing the field current required to maintain rated terminal voltage as the constant power factor load is varied is known as the *compounding* curve. The compounding curve at any other power factor can also be determined.
If the field current is held constant while the load varies, the terminal voltage will vary. Characteristic curves of terminal voltage can be plotted against armature current for any constant power factor load. The curve can be drawn for one value of field current which is usually the value required to give rated terminal voltage at rated armature current.
The variation of terminal voltage with load is due to the influence of armature reaction. When the power factor of the load is unity, the fall in voltage with increase of load is comparatively small. With an inductive load, the demagnetising effect of armature reaction causes the terminal voltage to fall much more rapidly.
In many industrial installations, fluctuations of load are heavy. Due to rapid variations of load from instant to instant, the voltage also fluctuates considerably, because of the varying voltage drop in the armature circuit. To overcome this unsatisfactory feature, automatic voltage regulators are usually provided to maintain the generator voltage reasonably constant in spite of the fluctuating load. The e.m.f is increased when the load is high and decreased when the load comes down.

Procedure:

I. Compounding Curve

Maintain motor speed constant throughout the experiment

1. Read the nameplate data and connect as shown in FIG.1
2. Start the prime mover D.C. Motor and bring the set to rated synchronous speed.
3. Adjust the field current to give rated voltage at the open circuit terminals of the synchronous generator.
4. Connect a resistive load and measure field current (required to maintain rated terminal voltage) for various load currents. Vary the load current in steps up to the rated armature current
5. Repeat item 4 above for an inductive load.

II. Volt-ampere Curve

Maintain motor speed constant throughout the experiment

1. Connect a resistive load.
2. Adjust the field current required to give rated terminal voltage at rated armature current
3. Measure the terminal voltage for various load currents, keeping the field current constant. Vary the load current in steps up to the rated armature current
4. Repeat for an inductive load.

Observations;

I. Compounding Curve

Terminal voltage =

Resistive load			Inductive load		
S.No.	Ia (A)	If(A)	S.No.	Ia (A)	If(A)

II. Volt-ampere Curve

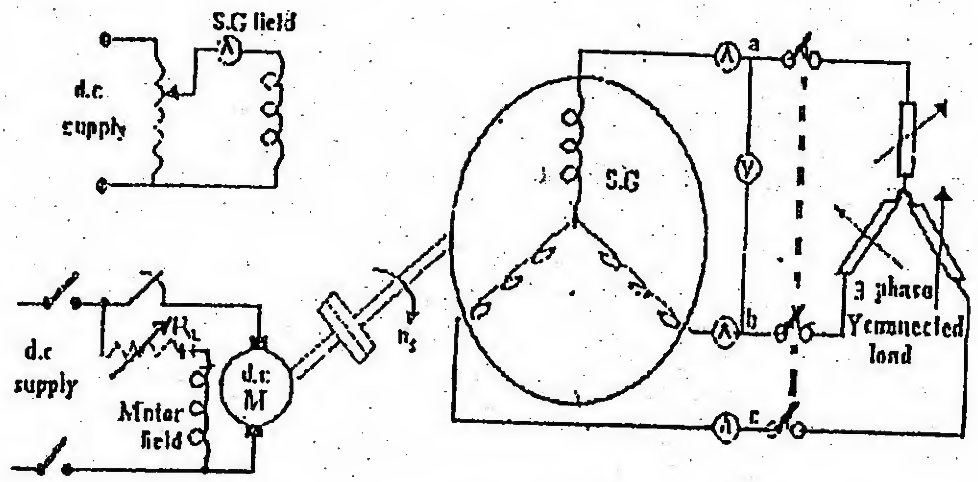
Field current =

Resistive load			Inductive load		
S.No.	Ia (A)	Vt (V)	S.No.	Ia (A)	Vt (V)

Report:

1. Plot the compounding curve and the volt-ampere characteristic of the synchronous generator and discuss their nature.

2. What practical steps are adopted to ensure that the voltage at the generator terminals, under varying voltage conditions, remain constant?
3. What is the effect of load power factor on the voltage regulation of the synchronous generator?



Connection diagram

(8)
Synchronisation of an Alternator

Objective:

1. To study the synchronisation of the given synchronous generator with the main busbars by Three-Dark-lamp method.
2. To study the effect of the change in input to the alternator (under constant excitation) on output power, power angle and power factor.

Theory:

The synchronous generator (FIG.1) can be connected to the busbars (represented by an equivalent generator) only when each of the voltages between R1 and R2, between Y1 and Y2, and between B1 and B2 is zero at every instant of time. This condition is fulfilled when the line voltages on the generator side are equal, at all instants of time, to the corresponding voltages on the busbar side. This is possible only if the following conditions are fulfilled:

a. The voltages Vg and Vb are equal in magnitude and are in phase.
b. Their frequencies are the same.
c. The generator and the busbars have the same phase sequence.

When these conditions are fulfilled, the synchronising switch between the generator and the bus can be switched on. Fulfilment of these conditions is checked by the following method:

I. Synchronisation by three dark lamp method

Connect the D.C. motor -synchronous generator as shown in FIG.2. Start the D.C. motor by switching on S1 and bring its speed to the synchronous speed of the generator. Adjust the field excitation of the generator using Rf2 so that rated voltage is obtained. Switch on the a.c mains switch S2 and adjust the variac so that Vb is equal to rated generator voltage. Let the phase sequence of the generator terminals RYB be the same as that of the respective terminals of the mains, RYB. The voltage phasors for this condition are shown in FIG.3.If the generator frequency is slightly more than that of the bus, then the phasors R1, Y1 and B1 move anti-clockwise relative to R2, Y2, and B2. The voltages across the lamps L1, L2, L3 (which are indicated by the phasors R1R2, Y1Y2, and B1B2) will increase & decrease simultaneously and therefore, the three lamps will brighten up and darken at the same time.

If the phase sequences are R1Y1B1 and R2 B2Y2, the phase diagram of voltages will be as shown in FIG.4. For this condition the voltages across

lamps given by phasors R1R2, Y1Y2 and B1B2 are not equal to each other at the instant shown.

Therefore the lamps go through their zero voltage one after the other. The phase sequences are thus different and can be corrected by interchanging any two terminals either on the generator side or on the bus side. When such a change is made *both the three-phase main switch S2 and the D.C. main switch S1 should be switched off.*

With the phase sequence corrected, if there is a large difference between the frequency of the generator and that of the bus, the lamps will brighten & darken in quick succession. By adjusting the speed of the generator, this rapidity can be reduced, which indicates that the frequencies are coming closer and the lamps will brighten up & darken slowly.

The correct moment of synchronisation in this method is when all the lamps are completely dark, at which time all the voltages of the bus are exactly in phase with the corresponding voltages of the generator. At this moment the synchronizing switch S3 is closed and the generator is synchronised with the mains.

After synchronisation do not allow the synchronous machine to run as a motor, i.e. do not allow the wattmeter to read negative. If it reads negative it means that the machine receives power from the a.c mains. In such a case, reduce the excitation of the D.C. motor so that the wattmeter reads a few positive watts.

II. Study of the influence of the change in input power of the synchronous generator

After synchronisation If is kept constant and the prime -mover excitation Ifpm is slowly decreased taking care that the positive power is shown by the wattmeter which indicates that the machine is only generating. For each value of Ifpm, Ia, W, V, and the power angle are noted. The power angle may be noted using a stroboscope. The generator may become unstable for higher values of current; care should be taken to switch off the a.c mains then.

Load of suitable values is connected to the D.C. busbar to absorb the D.C. power in the event the synchronous machine operates as a motor. This load is switched on before synchronisation.

Report:

Power output, P=

1. Calculate the power factor in each case, $\cos\phi = P/(1.73\ VI_a)$
2. Plot power P against δ (on X-axis) for different excitations.
3. Plot p.f against P (on X-axis) for different excitations.

4. Piot Ia against P (on X-axis) for different excitations.
5. Suppose lamps 2 & 3 were cross-connected as shown in FIG.5, how will the lamps glow for

- Correct phase sequence
- Incorrect phase sequence?

Draw phasor diagrams to justify your results.

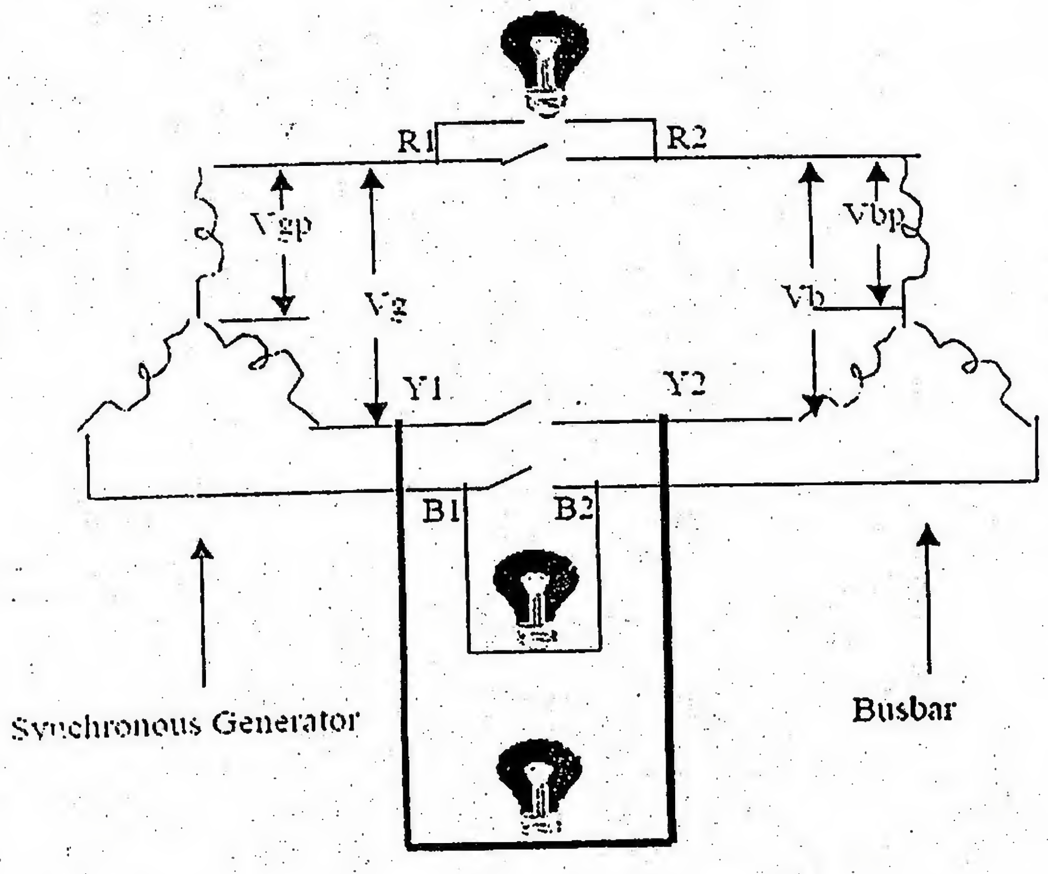
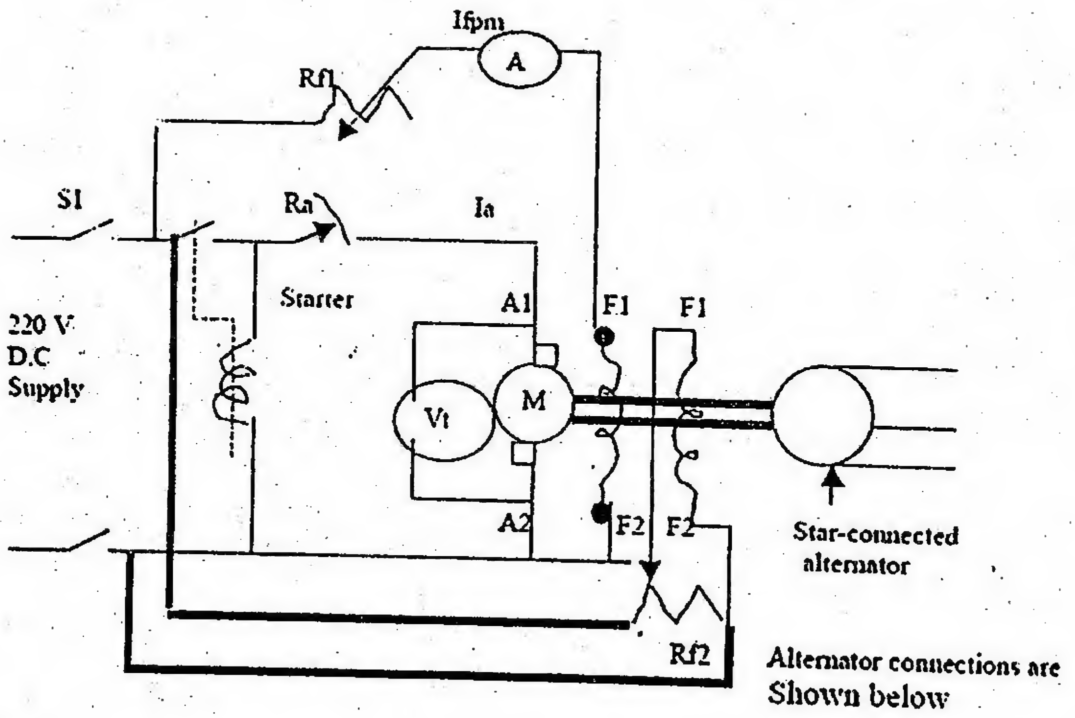
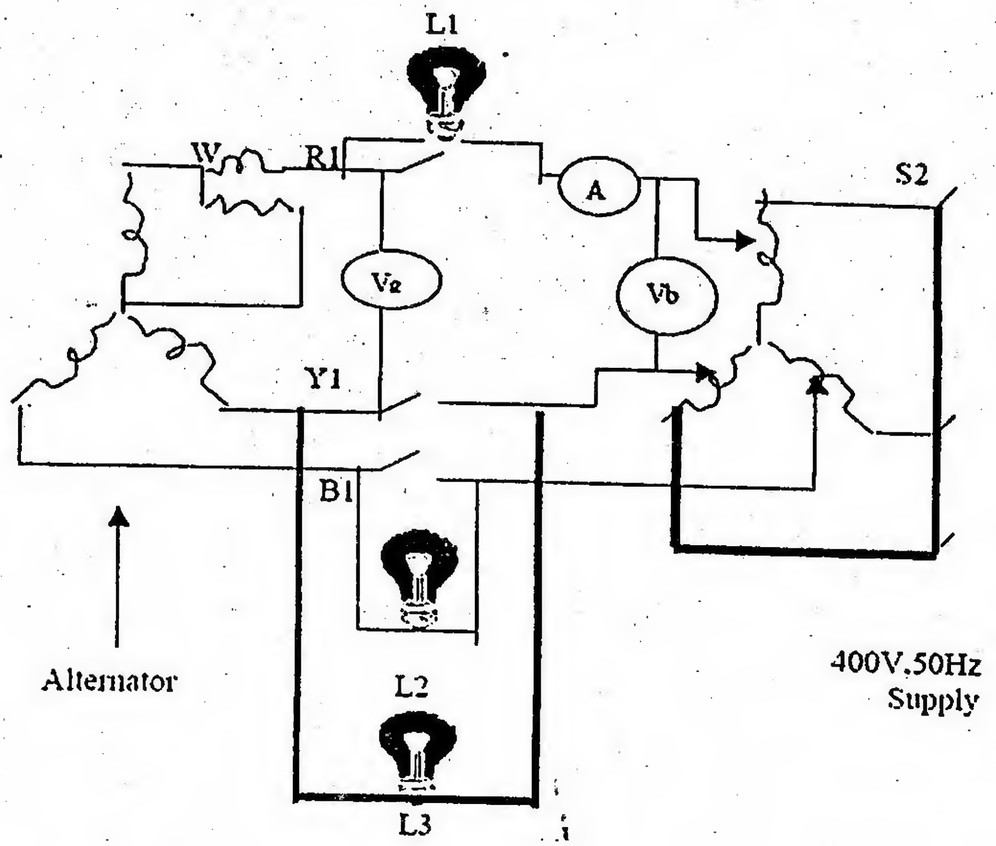


Fig.1


Ifpm
A
Rf1
S1
Ra
Ia
Starter
A1
F1
F1
220 V
D.C
Supply
M
Vt
A2
F2
F2
Star-connected
alternator
Rf2
Alternator connections are
Shown below


L1
W
R1
A
S2
Va
Vb
Y1
B1
Alternator
L2
L3
400V,50Hz
Supply

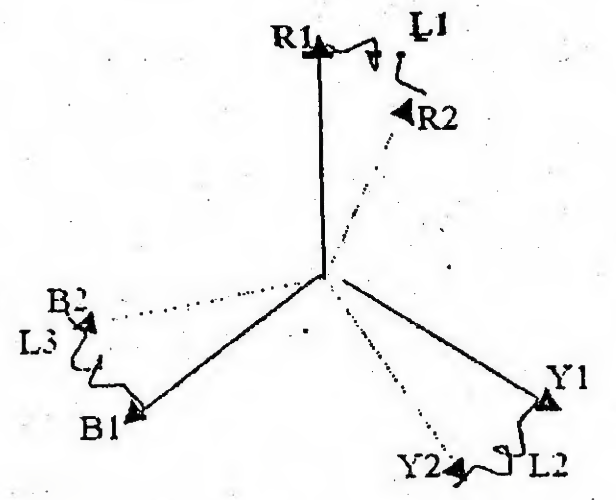


Fig.3

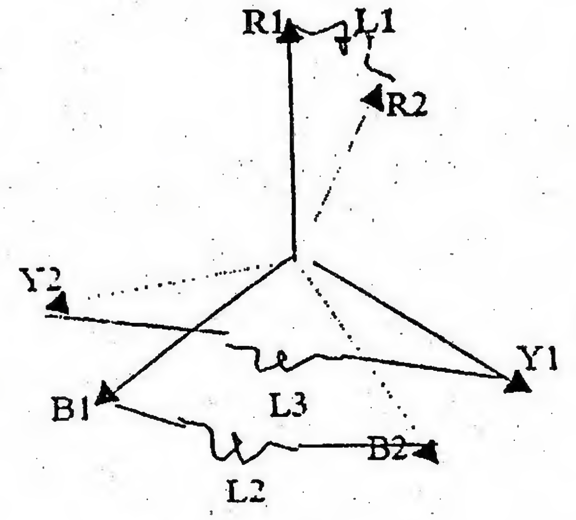


Fig.4

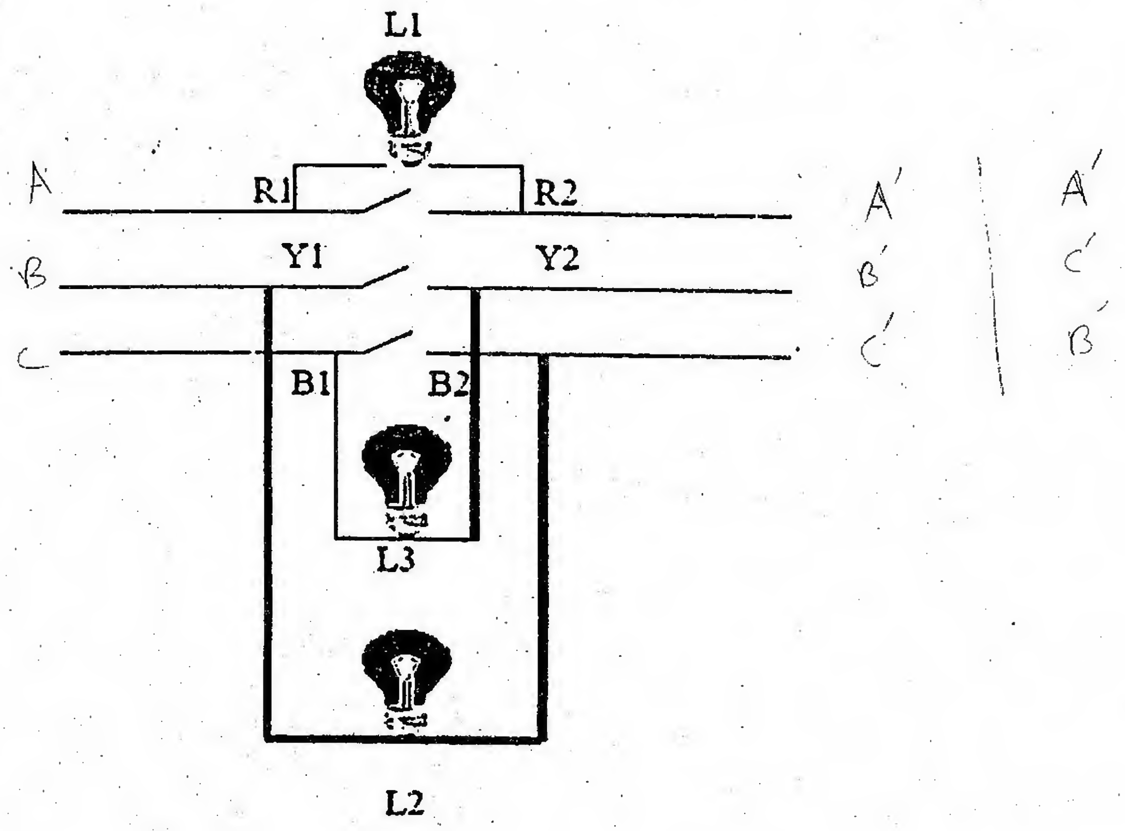


Fig.5

(9)
Parallel Operation of Alternators

Objective:

1. To study the transference of loads between two alternators running in parallel, keeping the load, frequency, and voltage constant.
2. To study the variation of voltamperes with respect to alternator excitation, keeping input power , output load, voltage and frequency constant.

Theory:

The conditions for successful parallel operation of alternator are:

1. The alternators shall have the same frequency
2. The alternators shall have the same induced voltage
3. The alternators shall have the same phase sequence
4. The alternator voltages shall be in phase.

The laod output of the alterantor is governed by the input power from its prime -mover. Variation of excitation gives rise to a change in the kVar ouput; the kW output remins unchanged.

Procedure:

1. The alternators are conneted as shown in FIG.1 using two single-phase wattmeters
2. The d.c shunt motors are started and the alternators are brought up to speed.
3. By varying the alternator fields, the terminal voltages are brought up to the rated values.
4. The speeds of the sets are adjusted by means of the motor field rheostat control until the alternators run at rated frequency
5. The synchronising switch is closed in the middle of a dark period of the lamps. (The alterantors should now be working in parallel, but they should not be delivering any load. Also, if the voltage and speed have been properly adjusted, there should be no interchange of current between the alternators and the ammeters should read zero.
6. For a particular load output at constant frequency and voltage, input to the d.c machine is varied and the outputs shared by each alternator are noted from the wattmeter readings. Inputs to the d.c side are also noted.
7. A graph is plotted between the input power and the load shared by each machine, as shown in FIG 2

8. Keeping the input power , outputload , terminal voltage and frequency constant, the current output of each alternator is noted for different excitaitons.
9. A graph of output (in VA) versus excitation as shown in FIG.3 is plotted.

Observations:

Wattmeter constants =
Voltage =

Frequency=
Load Current=

LOAD SHARING

No.	W1 (watts)	A1 (amps)	Iac1 (amps)	Vdc1 (Volts)	W2 (watts)	A2 (amps)	Iac2 (amps)	Vdc2 (volts)

Voltage =

Load current =
Frequency =
W1 =
W2 =

No.	Machine I			Machine II		
	If1(amp)	Iac1(amp)	1.73VIac1(VA)	If2(amp)	Iac2(amp)	1.73Viac2(VA)

Results:

S.No.	Machine I		Machine II	
	A.C Output,Watts	D.C Input ,Watts	A.C Output,Watts	D.C Input ,Watts

Remark:
Variation of load angle with change in the output load can be observed with a stroboflash arrangement

FIG.1 Two D.C motor -alternator sets as follows are used.

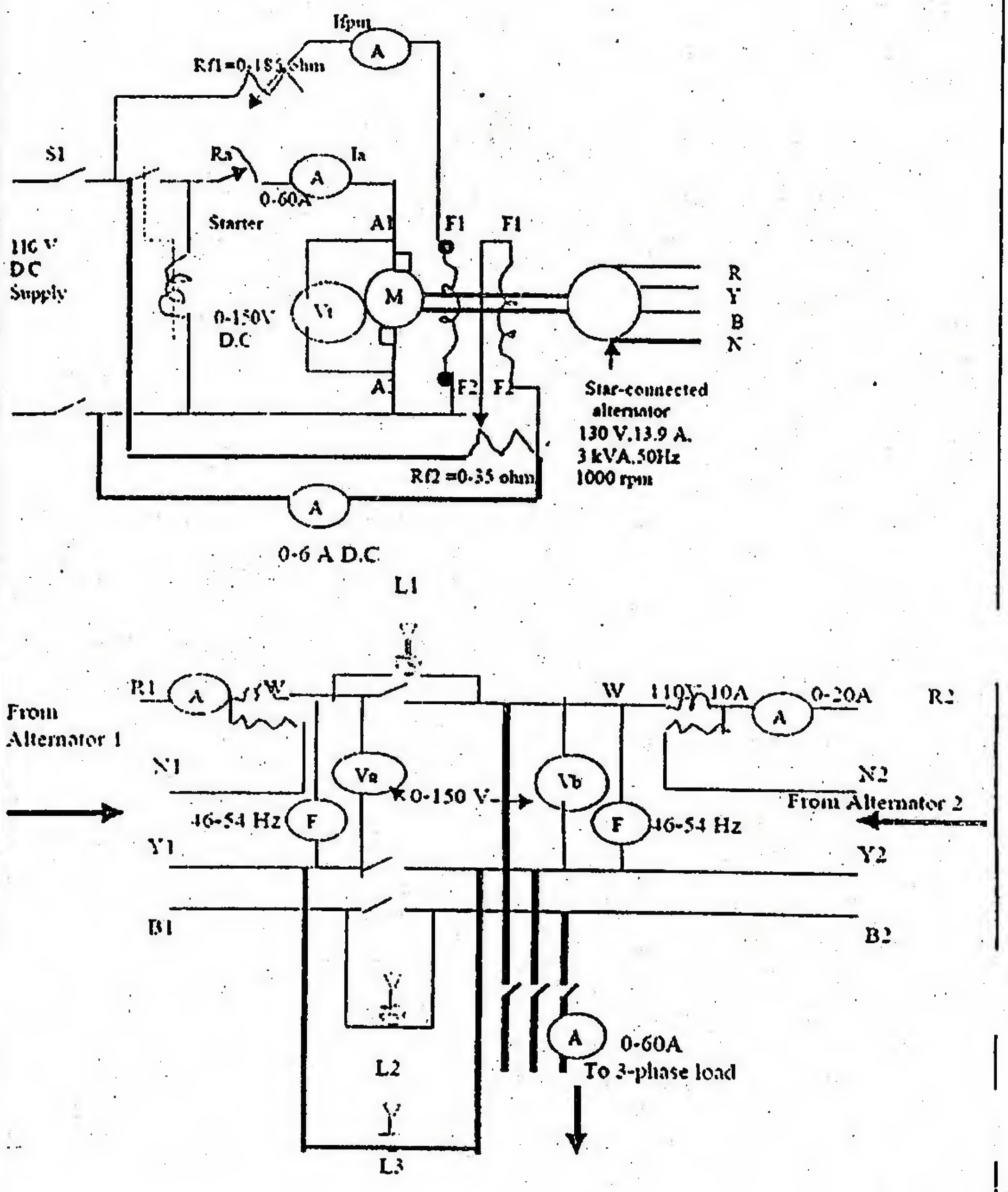


FIG.2

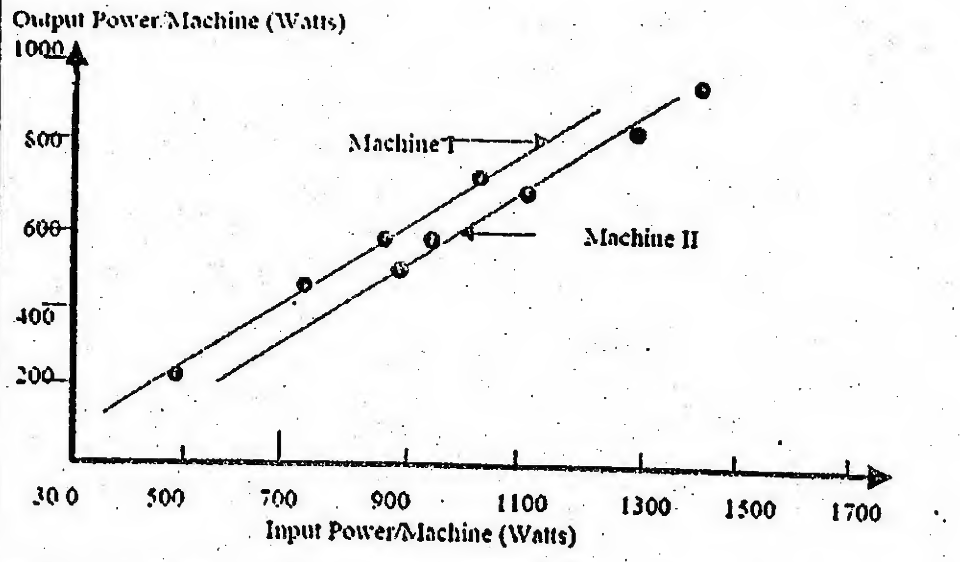
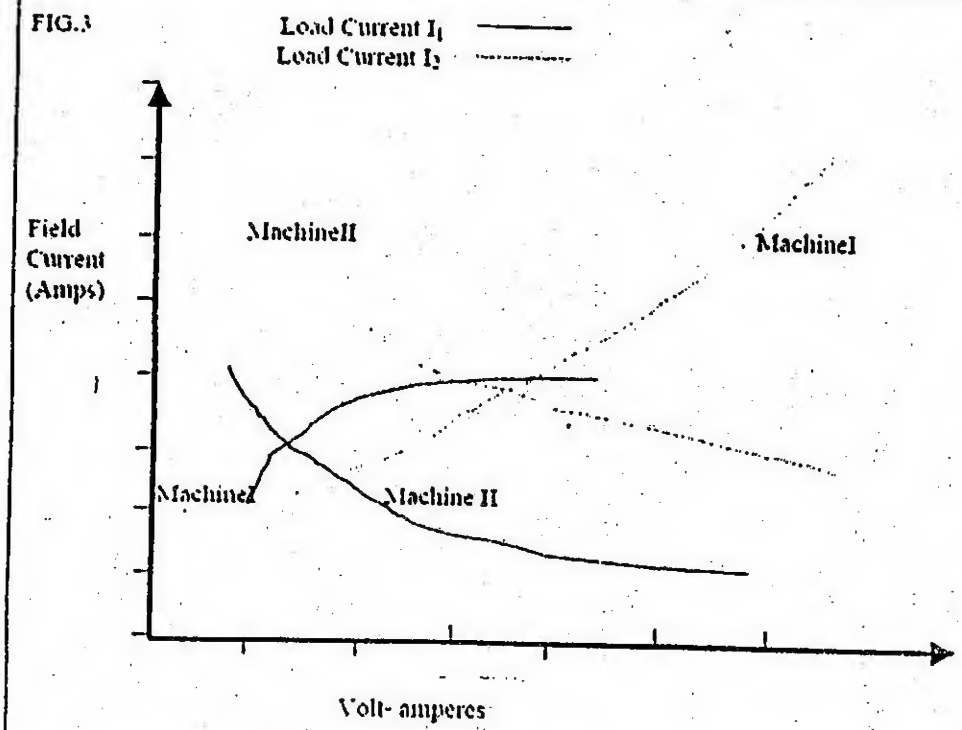

Output Power/Machine (Watts)
1000
800
600
400
200
Machine I
Machine II
30 0
500
700
900
1100
1300
1500
1700
Input Power/Machine (Watts)

FIG.3


Load Current I_1
Load Current I_2
Field Current (Amps)
MachineII
MachineI
MachineI
Machine II
Volt- amperes

(10)
Polyphase Connections and Synchronization of Alternators

Preliminary:

Take complete particulars of the alternator noting whether it has a rotating field or a rotating armature.

A- Poly-phase Connections.

Experiment (1):

The two ends of each of the phases are brought to separate terminals numbered as shown below.

Determine the terminals of each of the phases by testing for continuity using a battery and a lamp, or using an ohmmeter. Draw on the terminal board the determined connection diagram. Run the machine at the normal speed and determine the field current corresponding to a generated e.m.f. of 127 volts per phase. For all the subsequent tests the speed and excitation current should be kept at the above values.

1	2	3
×	×	×
4	5	6
×	×	×

Experiment (2) Star Connection:

1. Join any two terminals related to two different phases. Measure the voltage between the other two terminals of the same two phases.
   If it is $\sqrt{3}$ V phase (220 V) the connection is current. If it is otherwise, the connection of one of the phases should be reversed.
   Draw the vector diagram of this connection showing the phase voltages and the line voltage. Draw also the vector diagram of a faulty connection showing the phase and line voltages.
2. Join one terminal of the remaining phase to the junction point of the above two phases. Measure the voltage between the other terminal of this phase and the other two terminals of the other two phases. If the voltage are both equal to $\sqrt{3}$ V phase, the connection is current. If otherwise, the connection of the remaining phase should be reversed. Draw the vector diagram for this connection.

3. Disconnect the junction point and connect the other 3 terminals to form a new star point. Check that another star connection is obtained. Draw the vector diagram for this connection. What will be the phase difference between the line voltage in this connection and those in the last one?

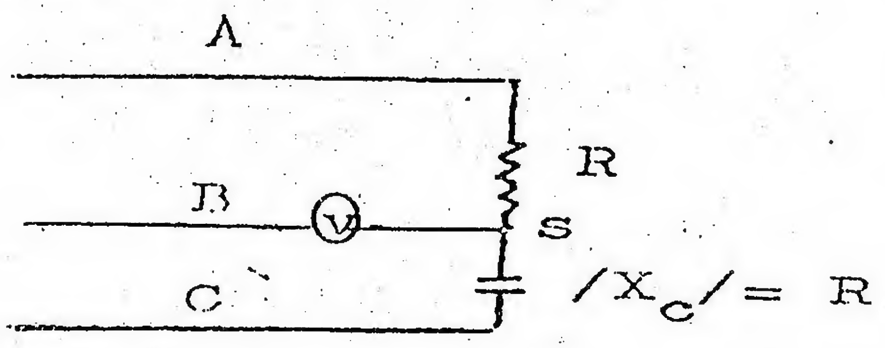
Experiment (3) Mesh or Delta Connection:

1. Disconnect the star connection in the last experiment.
2. Connect any two terminals related to two different phases, Measure the voltage between the other two terminals of the same two phases. If it is the same as the phase voltage, the connection is correct. If otherwise the connection of one of two phases should be reversed. Draw the vector diagram.
3. Connect one terminal of the remaining phase to any of the free terminals of the above connected two phases. Measure the voltage between the other terminal of this phase and the other free terminal of the above connected two phases. If it is zero, join them to have the mesh or delta connection. If it measures twice the voltage per phase, this shows that the connection is faulty and the connection of the last phase must be reversed before closing the delta connection. Verify the two cases and draw the vector diagram in both cases.

Experiment (4) Sequence of Phases:

Sequence of phases means the order in which the different phases of line voltages reach their respective maximum values.

1. To determine the sequence of the alternator phases connect it as in experiment (2) with a resistance and a condenser connected in series across one pair of lines as shown in the figure.

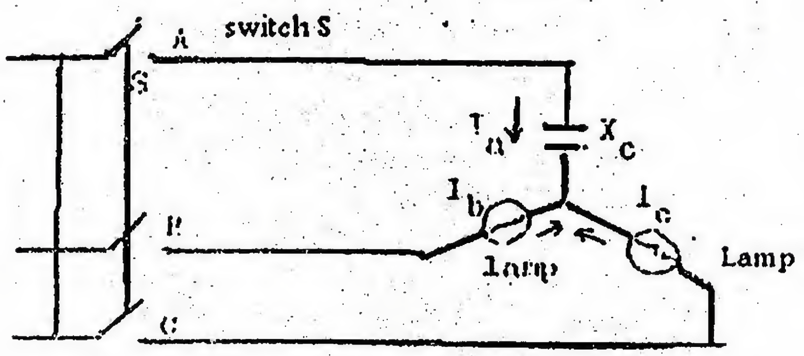


Measure the voltages across the resistance and the voltage between point s and the third line using a high impedance voltmeter.

If this voltage is less than the line voltage, the sequence of phases, for the connection shown is A-B-C. If it is more the sequence is A-C-B. Reverse the direction of the alternator, or simple interchange two of the lines, to ascertain the above statement.

Draw the vector diagram for the above circuit and explain why the sequence is as stated above.

2. Inspect the sequence – meter given and check that its design is the same as the shown circuit below. Connect it to the terminals of the alternator and increase the excitation to have a line voltage of 200 V, close the 3-phase switch s of the sequence meter and record the sequence related to the lamp which will illuminate stronger. Reverse the direction of the alternator or interchange two of the lines and record the sequence again? Prove the principle on which this sequence meter is operating.



B- Synchronization of Alternators:

Synchronization is the process of connecting an alternator in parallel with others already in operation (energized Bus-Bar). Before it is connected the following conditions must be satisfied:-

1. Equality of frequency.
2. Equality of voltage.
3. The same phase sequence.
4. Zero relative displacement.

With these requirements fulfilled, there will be no voltage difference between any corresponding pairs of terminals of M/C and bus-bars. So that such pairs can be electrically connected without disturbance.

Theory: As shown in Figures (1) and (2)

If the bus-bar voltage of the system is assumed to have the constant value V_b volt/phase, the voltage V_m of the incoming M/C will in general differ from V_b, both in magnitude and phase. While it is being brought up to the proper speed and excitation. If it is assumed that the incoming M/C is slowly accelerating but its speed falls short of synchronism, the relative angular velocity of phase V_m with respect to V_b is anti clockwise, in the direction marked slow. A voltmeter connected across the terminals of an open switch S will read the difference between V_b and V_m which varies from $V_b - V_m$ to $V_b + V_m$ at a frequency equal to the difference of frequencies of V_b and V_m. By regulating the speed of the incoming M/C and adjusting its excitation, V_m may be made to have the same magnitude and frequency, but it must be made to arrive this condition when V_m is in phase with V_b.

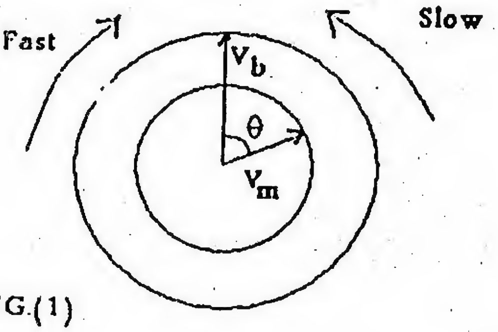
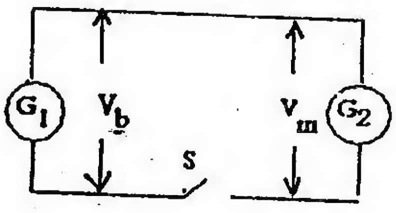


FIG.(1)



FIG(2)

Synchronism indicators:

The considerations outlined above show the need for a device which will indicate the exact moment for connecting the incoming generator to the main bus-bars, assuming that the operation is to be performed manually.

The most simple device for synchronization is the synchronizing lamps and voltameters.

There are 3 methods of connecting the synchronizing lamps known as:

Dark Method:

Connection diagram is as shown in (Fig. 3). When the two voltages are equal the frequencies are the same there may still be a phase difference between the voltages, in which case the lamps will glow steadily, further adjustment of the generator speed will then bring the two voltages into phase in which

case the lamps will remain permanently dark, and the generator can be connected to the bus-bars.

1. The alternator to be synchronized is brought up to approximately the synchronous speed. The lamps are connected as shown.
2. With $V_b = V_m$ the lamps will flicker with a frequency equal to the difference between the frequencies of bus-bars and generator. The voltages across the lamps are shown in the vector diagram (Fig. 4)
3. The switch S is to be closed at the instant when the 3 lamps are dark.

Rotating Method:
Connection and vector diagram are shown in Figures 5 and 6. With $V_b = V_m$ and the frequency of the generator is slightly different from that of the bus-bars the 3 lamps slowly brighten and darken in cyclic succession, in a direction depending upon whether the generator is fast or slow.
For the conditions of synchionization to be fulfilled (phase difference between V_b and $V_m = 0$) the lamp "a" will be dark and lamps b and c will glow (subjected to voltage = $\sqrt{3}\, V_{ph}$). At this instant switch S may be closed. This method has the advantage of showing weather the incoming M/C is running fast or slow, a condition which cannot be determined by the other two methods.

Bright Method: As shown in figures 7, 8 and 9.
Using a phase shifting network it is obvious that the phase angle between V_b and V_m is equal to zero when the lamps are subjected to maximum voltage = $2V_{ph}$. i.e. maximum brightness.

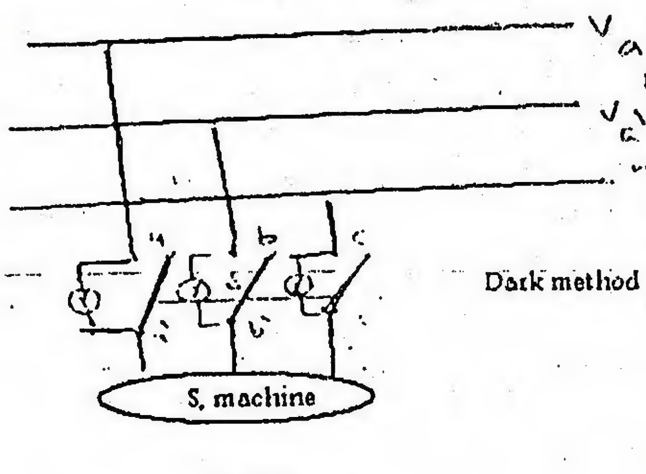


Fig. (3)

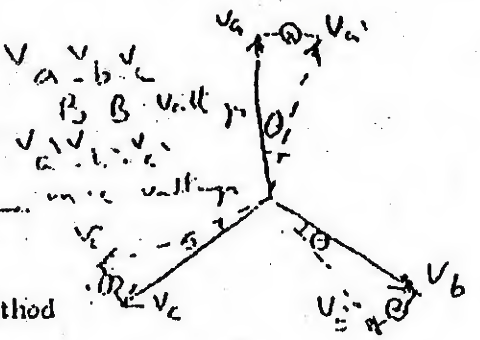


Fig. (4)

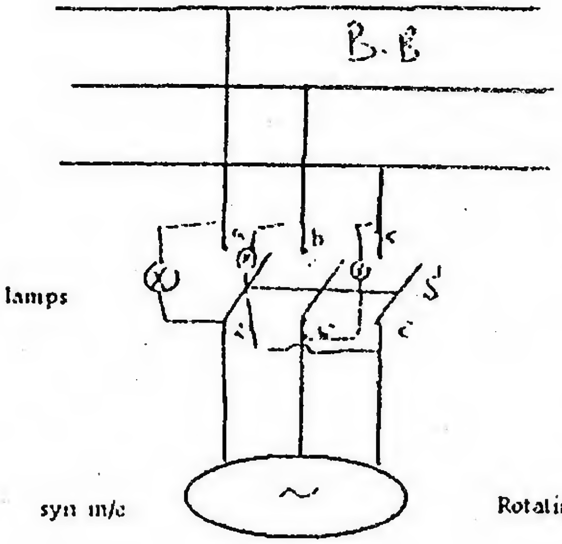
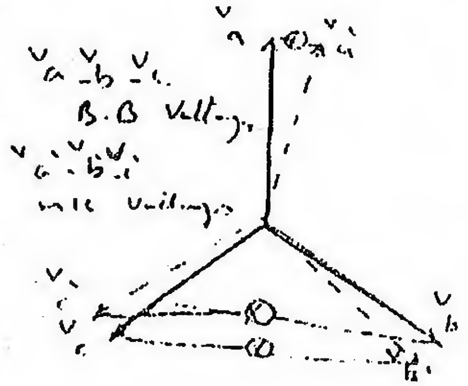


Fig. (5)



Rotating method

Fig. (6)

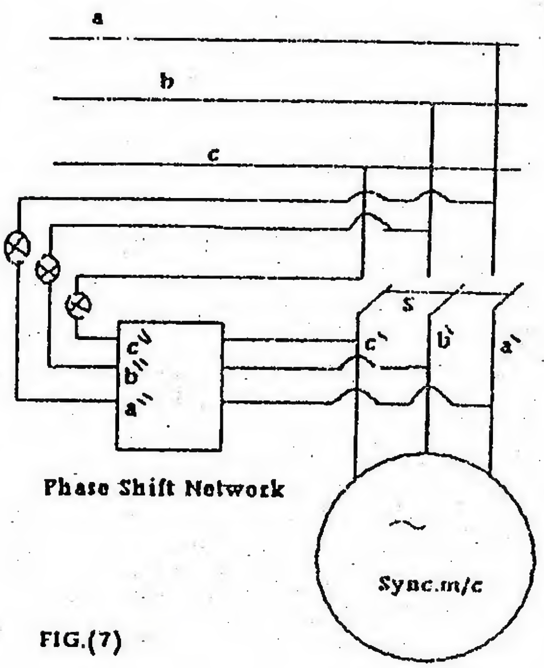


FIG.(7)

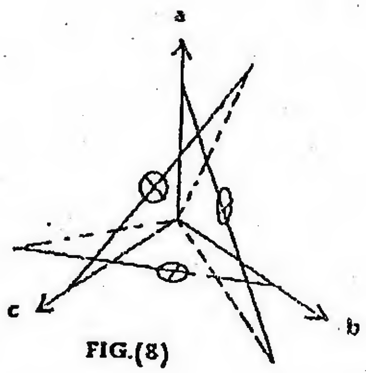


FIG.(8)

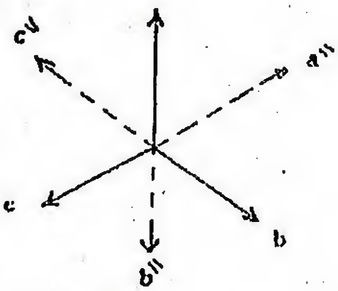


FIG.(9)

Bright Method

(11)
Direct & Quadrature axis Reactances of a Salient Pole Alternator

Objective:
To determine the direct & quadrature axis reactances of a salient pole alternator.

Apparatus:
1. Two A.C voltmeters
2. One A.C ammeter
3. Rheostats
4. A single throw triple pole switch

Theory:
The unsaturated values of Xd and Xq for a 3-phase synchronous machine may be found by applying low values of balanced voltage to its armature, and driving its rotor mechanically at a speed differing slightly from the normal synchronous speed, the field circuit being open. The rotating armature m.m.f axis gradually changes, on account of the 'slip ' between coincidence with the polar & interpolar axes successively. The reluctance of the magnetic circuit varies cyclically between an upper & a lower limit, and the armature current consequently changes in the reverse sense. The ratios of applied voltage to armature current gives the synchronous reactances, using minimum ratio for Xq and maximum for Xd. Xd has the same value as would be obtained from the normal no load and short circuit tests.

Procedure:
1. A coupled D.C motor very near to synchronous speed runs the salient-pole synchronous machine. If the synchronous speed is 1500 rpm, the set is run at 1750 rpm.
2. The stator of the salient pole alternator is supplied from a low voltage (20%-30% of rated voltage), 3 -phase supply. The supply frequency is more than 50 Hz as the supplying alternator is run at 1750 rpm.
3. The field is kept open and the maximum and minimum deflections in the meters (to read the supply voltage and current) are read.
4. Xd, Xq are calculated.

Results:

$$X_d = \text{Maximum V/Minimum I}$$
$$X_q = \text{Minimum V/ Maximum I}$$

Discussion:

1. The alternator should not be run at exactly the synchronous speed, for then instruments will give steady deflections. The stator voltage must be capable of close adjustment. The slip must be very small. Otherwise the measurements will be in error on account of eddy currents in the pole faces or the damper windings.

   If in the experiment, the slip is very large, and cannot be adjusted to a smaller value, he measurements are liable to error.

2. The slip tends to pulsate because of fluctuation of torque with the relative pole positions with the result that there is a tendency for Xd to be underestimated.

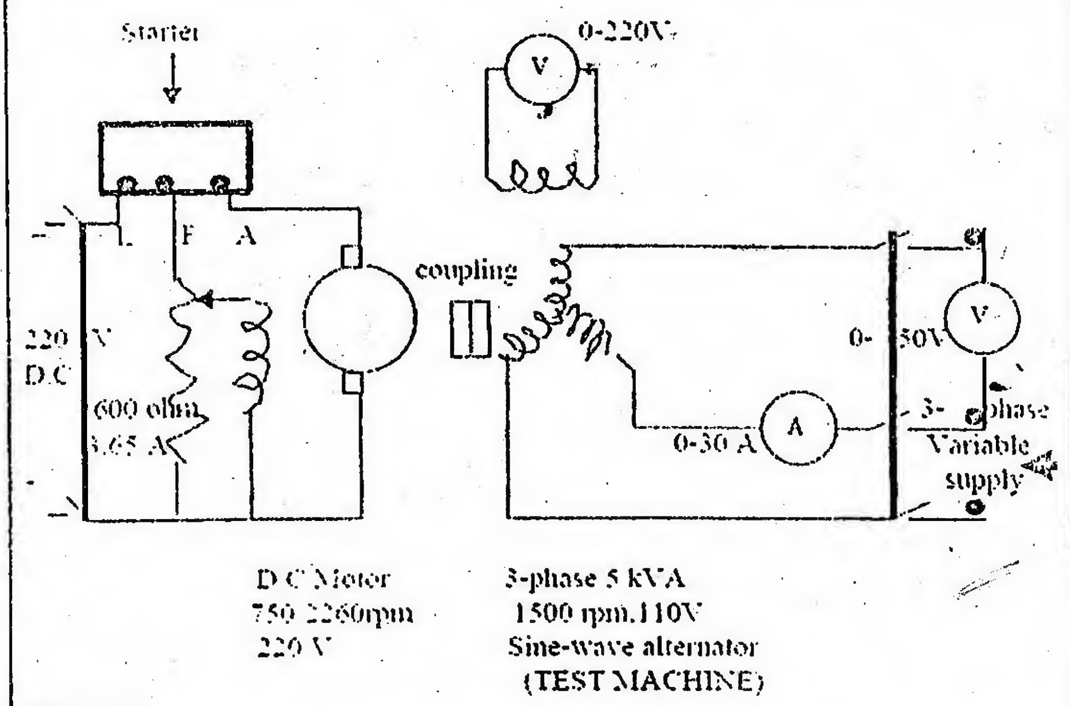

Starter
0-220V
F A
coupling
220 V
D.C
600 ohm
0.65 A
0-
50V
0-30 A
3- phase
Variable
supply
D.C Motor
750 2260rpm
220 V
3-phase 5 kVA
1500 rpm.110V
Sine-wave alternator
(TEST MACHINE)

FIG.1 (a)

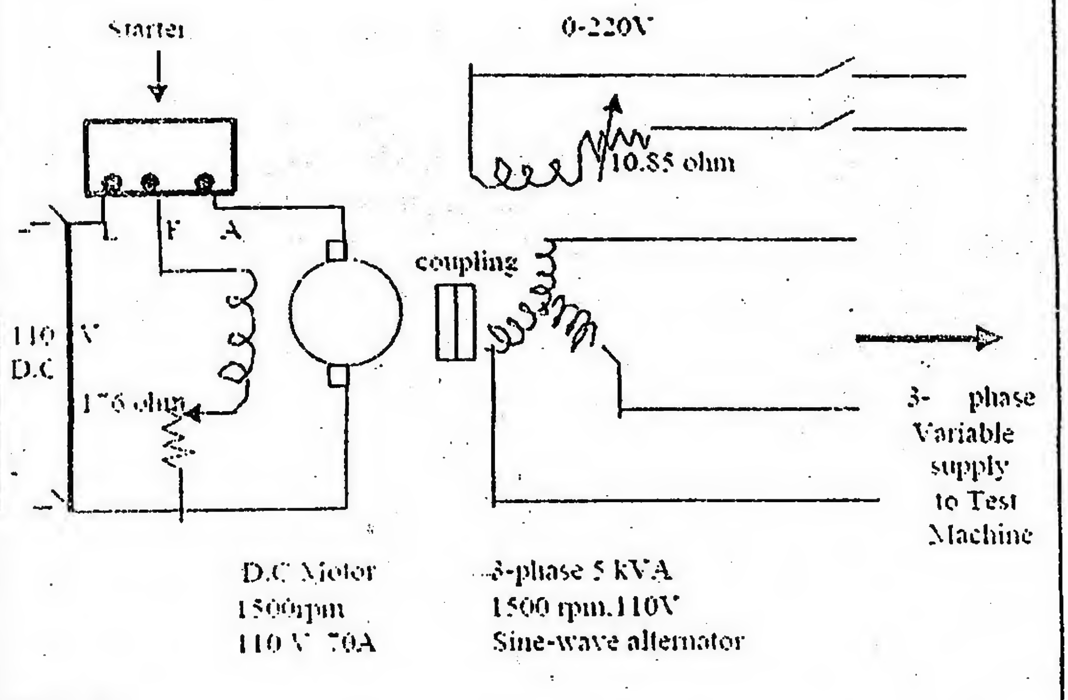

Starter
0-220V
10.85 ohm
F A
coupling
110 V
D.C
176 ohm
3- phase
Variable
supply
to Test
Machine
D.C Motor
1500rpm
110 V 70A
3-phase 5 kVA
1500 rpm.110V
Sine-wave alternator

FIG.1 (b)

(12)
The V. Curves of Synchronous Motor

The V. curves of synchronous motor are the family of curves representing the relationship between the armature current and the field current at constant supply voltage and electromagnetic power (P_g).

Since in the synchronous machine we have $T = \frac{0.973}{n_s} P_g$ kg.m., so the torque is proportional to the air gap power, and the V. curves can be developed as the relationship between the armature current and the field current for constant supply voltage and constant developed torque.

Theoretical approach:

a- Circle diagram for constant developed torque and variable field current:

Considering the synchronous motor, the power input per phase is

$$P_{in} = VI_a \cos \Phi \tag{1}$$

And the electromagnetic power P_g which is proportional to the developed torque of the machine is

$$P_g = VI_a \cos \Phi - I_a^2 r_a \tag{2}$$

Consider (Fig.1), let OL be the current I_a which corresponds to a fixed torque at a fixed field current. Then with a point M_T on the axis of ordinates chosen so that

$$OM_T = \frac{V}{2r_a} \tag{3}$$

From the diagram

$$I_a^2 \sin^2 \Phi = R_T^2 - (OM_T - I_a \cos \Phi)^2 \tag{4}$$

From 1, 2, 3 and 4 we have

$$VI_a \cos \Phi - I_a^2 r_a = \frac{V^2}{4r_a} - R_T^2 r_a = P_g \tag{5}$$

In order that this power P_g i.e. the torque remain constant and independent of the value of the field current, the quantity

$$\frac{V^2}{4r_a} - R_T^2 r_a = \text{constant} = P_g \qquad (6)$$

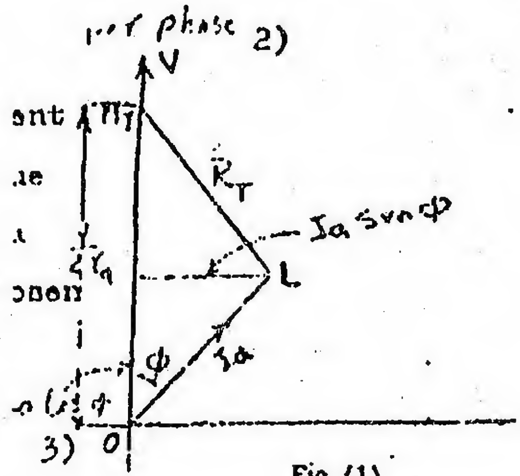


Fig. (1)

Since V and r_a are constants, the quantity R_T must also be a constant for the torque (i.e. P_g) to remain constant.

By changing the field current, so the armature current changes and the locus of the stator current (point L) for constant torque and variable field current is a circle with R_T as the radius and M_T as the center point and $OM_T = \frac{V}{2r_a}$

Solving (equ. 6) for this radius R_T corresponding to different values of constant torque

$$R_T = \sqrt{\frac{V^2}{4r_a^2} - \frac{P_g}{r_a}} \qquad (7)$$

The radius R_T which corresponds to zero torque i.e. $P_g = 0$ is

$$R_{T_o} = \frac{V}{2r_a} \qquad (8)$$

(Fig. 2) solve several circles for different values of constant torque

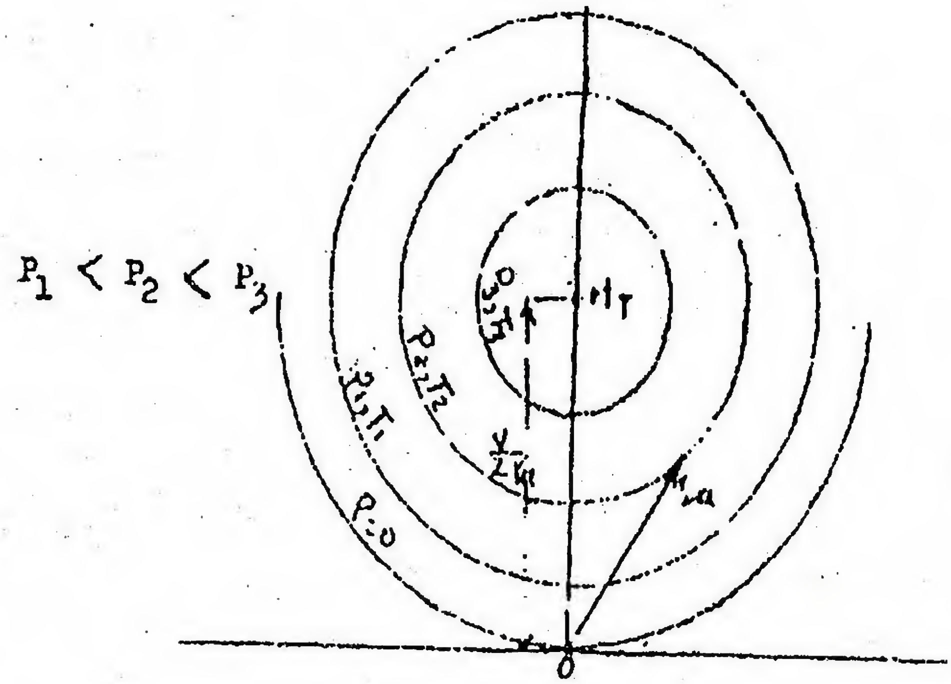


Fig (2)

b- Circle diagrams for variable torque and constant field current:

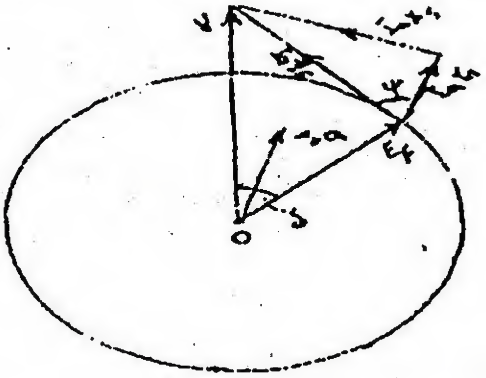


Fig. (3)

(Fig. 3) shows the vector diagram for a motor operating with a lagging current, the vector $I_a Z_s$ is ψ degree ahead of the current vector I_a

where $\tan \Psi = \frac{x_s}{r_a}$

for the synchronous motor

$$\dot{V} = -E_f + I_a Z_s \tag{9}$$

then $$V = E_f \angle -\delta + I_a \angle -\phi\ Z_s \angle \psi \tag{10}$$

$$= E_f \angle -\delta + I_a Z_s \angle \psi - \phi \tag{11}$$

where δ = power angle

Since the supply voltage is constant, if the torque is varied at const. field current; the magnitude of vectors V and E_f will not be changed, but the torque angle δ will change.
Therefore the vector $I_a Z_s$ changes and with it the armature current I_a changes also. From (Fig. 5), it can be seen that when δ varies, the locus of E_f is a circle with the origin O. The min. value of $I_a Z_s$ is

$$I_a Z_{s(min)} = V - E_f \tag{12}$$

and the max. value of $I_a Z_s$ is

$$I_a Z_{s(max)} = V + E_f \tag{13}$$

and these two values coincide with the direction of the voltage V. The end point of the vector $I_a Z_s$ moves on a circle, and the vector $I_a Z_s$ is Ψ degrees ahead of the current vector I_a.
Therefore the min. and max. values of $I_a Z_s$ lie [i.e. Ψ degree] behind the terminal voltage V.
So in (Fig. 4), if the line OG is drawn behind the supply voltage V by an angle Ψ, then $I_{a(min)}$, and $I_{a(max)}$ lies on this line, and have the values

$$I_{a(min)}\ \frac{V - E_f}{Z_s},\ \text{and}\ I_{a(max)}\ \frac{V + E_f}{Z_s} \tag{14}$$

If $OP_1 = I_{a(min)}$ and $OP_2 = I_{a(max)}$, then P_1P_2 is the diameter of the circle on which the end point if I_a moves and point M is the center of the circle. Thus the diameter of the circle is

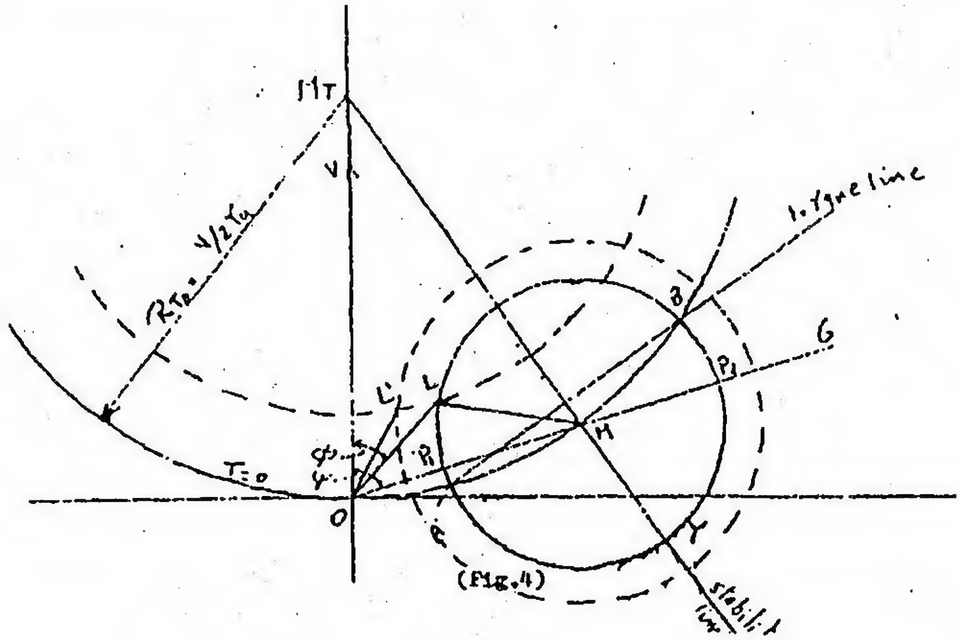
$$D = I_{a(max)} - I_{a(min)} = \frac{2E_f}{Z_s} \tag{15}$$

and the radius of the circle is $R = \frac{2E_f}{Z_s}$ 1. (16)

$$OM = I_{a(max)} - R = \frac{V}{Z_s} \tag{17}$$

The diameter of the circle increases with increasing field current ($D \alpha E_f$) and when the field current is zero the circle becomes a point coinciding with point M and this point represents zero torque.

In Fig. 2, the circle for T = constant and variable field current is shown. It comprises all possible values of field current including the field current for which the circle of variable torque (Fig. 4) is drawn. So in (Fig. 4), if a circle is drawn with radius $R_{T0} = \frac{V}{2r_a}$ from a center M_T, this circle intersect the circle of variable torque in two points A and B for which the torque is zero.



The line AB is the torque line and the machine operates as a motor on the arc AB above the torque line and as a generator on the arc AB below it, so if OL represents the armature current I_a, then from (16, 17) we have

$$LM = \frac{E_f}{Z_s} \qquad \text{and } OM = \frac{V}{Z_s}$$

Then for a constant developed power (const. torque), OL and OL' represents currents I_a and I_a' for corresponding E_f and E_f' or I_f and I_f' respectively. In this way, the correlation between I_a and I_f can be found for any constant developed torque.

Construction of V. curves

The V curves can be constructed by two methods

1- Applying the previous theoretical method.

2- Using pure experimental results.

1- Applying the previous theoretical method

In This method we need the value of r_a and z_s of the machine and also the value of the const. supply voltage. The armature resistance per phase r_a can be measured using the d.c. ammeter voltmeter method. This value of the d.c. resistance has to be modified to account for the temp. rise of the machine and the skin effect.
The synchronous impedance z_s can be determined using the results of no-load and short – circuit tests. As the value of the synchronous impedance is not constant, then for simplicity the saturated value of z_s will be taken.

a- Plot the relation between I_a and I_f for different values of const power.
b- On the same graph and for the same values of constant power in part a, plot the relation of P.f. and I_f.

2- Using pure experimental results

The V-curves can be determined by a pure experimental work as follow: The synchronous motor under test is coupled to a d.c. shunt machine. The d.c. machine is used to start the synchronous motor and after synchronizing, it works as a load to the synchronous machine after connecting it to a variable resistance box.

1- Draw the connection diagram for such experiment to read V, I_a and W_{in} input power of the synchronous motor. Also the values of $I_{d.c.}$ and $V_{d.c.}$ of the d.c. machine.

2- For constant output of the d.c. machine (i.e. constant $I_{d.c.} \times V_{d.c.}$ change the field current of the synchronous motor and read for each value of I_f, the values of I_a , W_{in} calculate also for each value of I_f the p.f. of the synchronous motor and the total efficiency of the set (synchronous motor and d.c. generator) as $\frac{V_{d.c.} \times I_{d.c.}}{W_{in}}$

3- Repeat step (2) for another value of constant $V_{d.c.} \times I_{d.c.}$ such as ¼, ½, ¾, 1 and 1 ¼ full of the d.c. machine.

4- Plot the values of I_a, W_{in}, efficiency, p.f. with respect to the field current of the synchronous motor.

5- Compare the results obtained in this test with that obtained using the theoretical approach.

6- Give a full discussion for your obtained results.

7- In your report answer the following:

a- State the methods used for starting synchronous motor.

b- What is meant by hunting in synchronous machines and how it can be reduced?

c- In what condition the unity power factor would be unstable.

d- How it can be known that the synchronous motor changes its power factor by observing the reading of the input wattmeter.

(13)
Synchronous Motor Characteristics

Objective:

The purpose of this experiment is to obtain the performance characteristics of synchronous motor operating from infinite bus. The performance is to be studied with

1. Constant excitation & variable load
2. Variable load and excitation with constant input power factor
3. Constant input power and variable excitation

Starting

The motor can be started as an induction motor and then 'pulled into step' by switching on the excitation. The synchronous motor /DC generator set is connected as in FIG.1. The motor is started as an induction motor with a star-delta switch. Since the starting current will be large the triple –pole short-circuiting switch SCS is closed before switching on the 3-phase mains switch and also the load on the DC generator is kept zero. Switches S1 & s2 are closed. Then the star-delta switch is operated. The switch should be put on to the delta position only after allowing the machine to come up to speed in star position for sometime thereby reducing the current. In delta position, the excitation is arranged to be automatically on and the excitation is controlled by the SG6 potentiometer.

Procedure

1. **Constant excitation, variable load**

a. Start & run the synchronous motor on no load. Adjust the excitation If for normal excitation and keep this constant. Vary the load slowly and note V1,I1,W1 and W2,

b. Repeat for an under-excitation & an over -excitation.

2. **Constant power factor and variable load excitation**

a. Keep zero load on the generator. Adjust the excitation so that the power factor is unity (by making wattmeter reading W1 equal to W2, both readings being positive). Load the machine gradually, each time adjusting the power factor to unity. Note the field current If and the motor current IL

b. Repeat for constant 0.5 p.f lagging & constant 0.5 p.f leading. Since the phase sequence is RYB, 0.5 p.f leading is obtained when W2 is zero and 0.5 p.f lagging is obtained when W1 is zero.

3. **V-curves with constant input power**

a. Load the synchronous motor and keeping the a.c input power (W1 +W2) constant , vary the excitation and note IL and If

b. Repeat for another value of a.c input power.

Report:

a. Calculate the power factor using the readings of W1 and W2 (for Part 1 of the experiment). Plot IL and power factor separately against a.c power input on x-axis.

b. For Part 2 of the experiment, plot If against IL on x-axis.

c. For Part 3 of the experiment, plot IL against If on x-axis.

d. By using the general locus diagram (e.m.f loci) and O.C.C show how the V-curves can be obtained theoretically.

e. Using phasor diagrams, prove the statement made in 2(b) above.

FIG 1

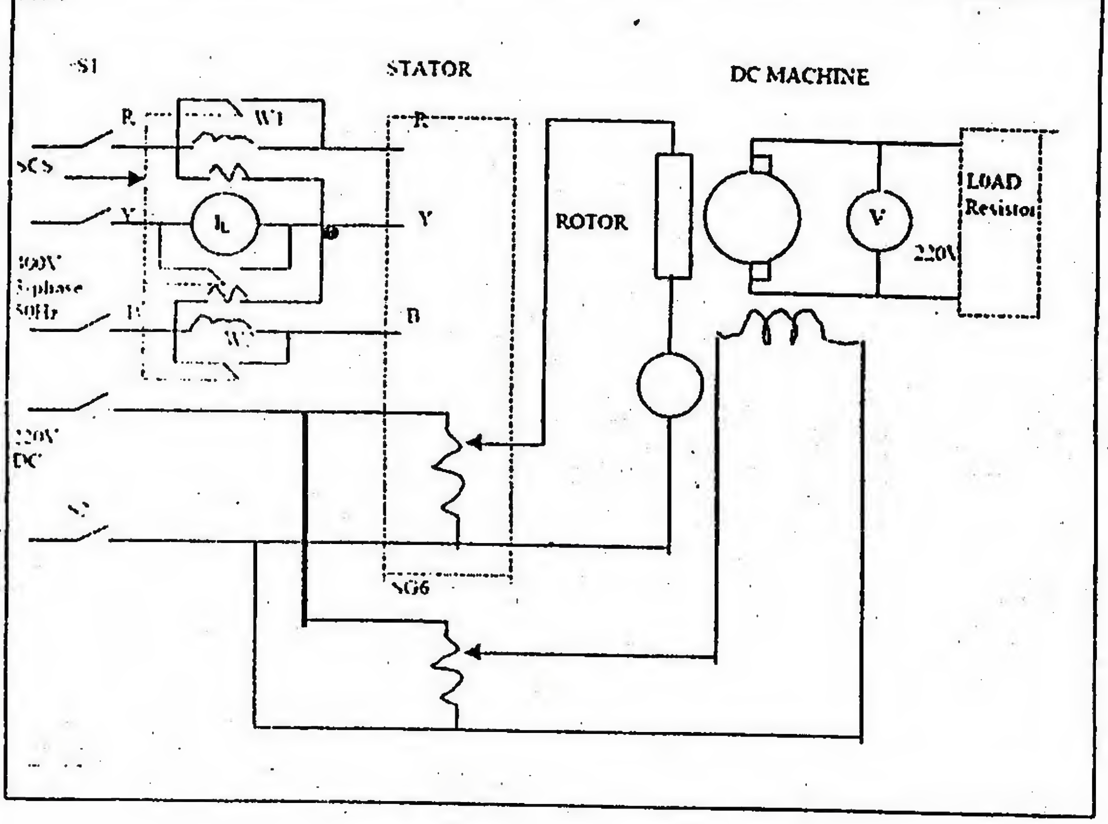
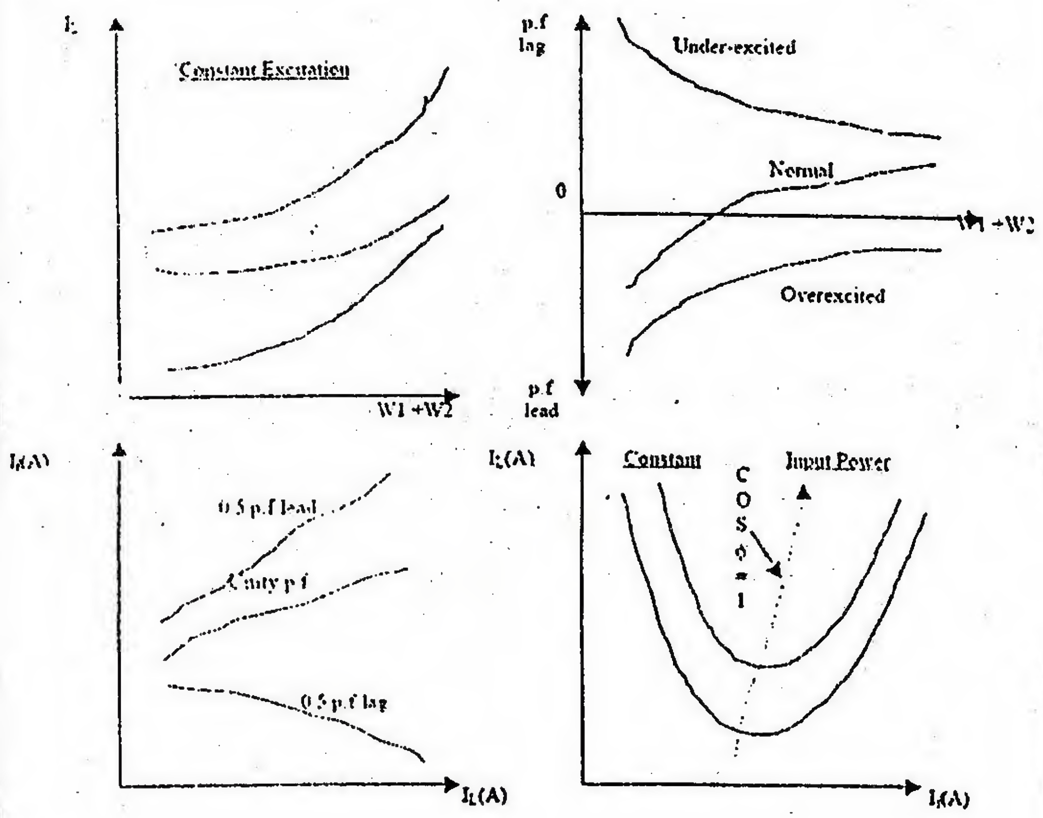


FIG.2



I_L
Constant Excitation
W1 +W2
p.f
lag
Under-excited
Normal
0
W1 +W2
Overexcited
p.f
lead
I_f(A)
0.5 p.f lead
Unity p.f
0.5 p.f lag
I_L(A)
I_L(A)
Constant
Input Power
C
O
S
ϕ
=
1
I_f(A)

(14)
Load Characteristics of Synchronous Motor

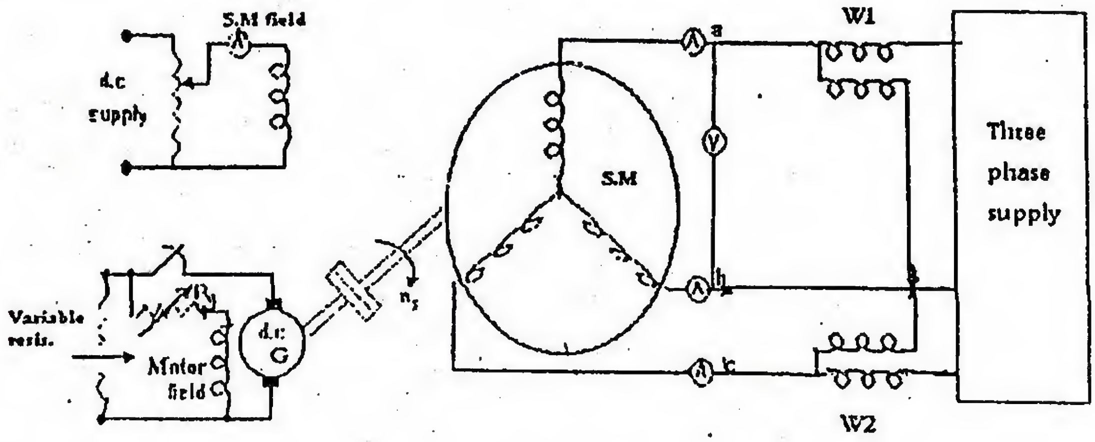
Object:

It is desired to find the relation between the efficiency of a synchronous motor, its power input, output, ...etc and its load current (input or armature current).

Experiment:

(1) The d.c. armature resistance $r_{a.d.c.}$ of the synchronous motor measured using the ammeter-voltmeter method. The a.c armature r_a is obtained by modifying the d.c. resistance to allow for the skin effect of the power frequency.

(2) Use the d.c directly coupled machine to start the synchronous motor. First the d.c machine is used as a motor to drive the synchronous machine as a generator, which will be synchronized to the 3-phase a.c. supply. Disconnect the d.c. motor from the d.c supply and connect its terminals to a variable resistance. The d.c machine will operate as a generator and represent the load on the synchronous.



Connection diagram

(3) Connect the circuit as shown in figure. Increase the power input to the synchronous motor from its no-load value by varying the value of the load resistance connected across the terminals of the d.c generator.

(4) Take Simultaneous reading of wattmeters W_1 and W_2, ammeter reading the current input to the synchronous motor, speed and the supply line voltage. The synchronous motor field current I_f is kept constant through the experiment.

(5) The power input to the synchronous motor is calculated as

$P_{inp} = W_1(+or-)\ W_2$ [w]

While the power output from the synchronous motor is given as

$P_{out} = P_{inp} - 3*I^2_a * r_a$ – constant losses [w]

While I_a = armature current of synchronous motor [A]

r_a = armature resistance [ohm]

The constant losses (Iron losses + Mechanical losses) for the synchronous motor, may be taken for simplicity as

Constant losses = ½ Power Input to the S.M. at no-load [w]. Assuming that no-load losses are equally divided between synchronous motor and d.c generator.

(6) Draw a curve showing the efficiency of the synchronous motor $\eta_{S.M.} = P_{out} / P_{inp}$ against the armature current I_a.

(7) Draw also curves showing the variation of the losses with the armature current I_a of S.M.

(8) Using the measured and calculated values, draw speed, P.F., I_a, P_{inp}, P_{out} and η as function of load torque.

Discussions:

(1) Comment on the shape of the curves obtained.

(2) At what armature current I_a does the maximum synchronous motor efficiency occurs?

(3) Does the speed of the synchronous motor change with the change in the load on its shaft?

(4) What are the disadvantages of using synchronous motor in industry?

(5) How does the speed change with increasing load?

(6) How can the direction of rotation of synchronous motor be reversed?

(15)
Back to Back test of Transformers

A-Introduction:
The object of testing the transformer is to determine whether or not it can give safe and satisfactory performance when in use.
The electrical tests needed may be classified as:

1-Loading characteristics:
That is to obtain the efficiency and regulation of the transformer under different load conditions.

2-Heat run test:
To determine whether the temperature rise of the transformer under normal load condition is within the prescribed limits. This is done by allowing a full load current to flow in the transformer windings for a sufficiently long period until a steady temperature depending upon the transformer rating is reached. (The time increases with the transformer rating). This time ranges between 3 and 24 hours.
The above tests can be carried out by direct measurements, i.e. by: applying an actual load (Rheostats) to the transformer and measuring the input and output power as well as the temperature rise, assuming that the loading rheostats are available.
However it is not practical to apply actual loads especially in the case of large transformer for the following reasons:

1- As concerning the two tests the rheostats required to absorb the power would be too large and costly, as well as dangerous to handle in case of high voltage.

2- With respect to the heat run test it is too expensive to supply the power for such long periods.

A method of testing applicable to any size of transformer without loading them directly, known as the back or the opposition test, can be carried-out providing that two identical transformer are available.

Back to Back test of single phase transformers.
Theory:

The two identical transformers are connected in parallel on the low tension side to a source having a voltage equal to the rated low tension voltage. The two high tension windings are connected is series to an auxiliary circuit having adjustable voltage (auxiliary transformer) in such a way that the e.m.fs induced in the two high tension windings are in opposition around the series circuit (Fig. 1).

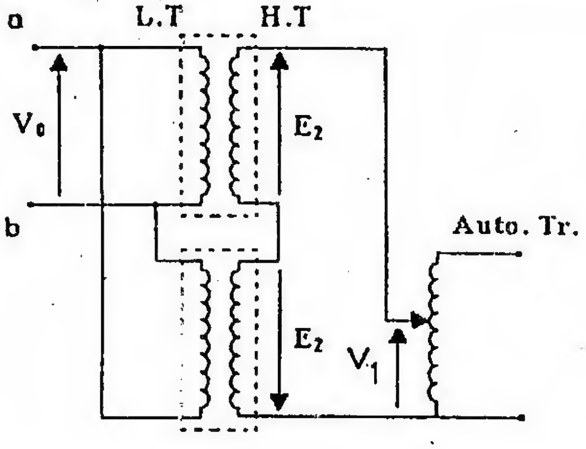


Fig. 1

When the adjustable voltage $V_1 = 0$, the two high tension e.m.fs E_2 balance each other and no current will flow in the secondary circuits. The currents in the low tension windings will be the exciting currents, and the supply circuit (Source ab) will furnish the core loss of the two transformer together with the copper loss caused in the low tension windings due to the magnetizing currents. So if P_o and I_o are the power and current draw from the supply with $V_1 = 0$

$$P_o = 2\,P_{ir} + \frac{I_o^2\, r_1}{2}$$

where P_{ir} is the iron losses of one transformer. And r_1 is the active resistance of the low tension winding of one transformer.

On gradually increasing the auxiliary voltage "V_1" in the series circuit any desired amount of current may be made to flow in the high tension windings. In the low tension windings which are short circuited w.r.t. the high tension windings, there will then flow currents greater than those in the other windings by the ratio of transformation. The power supplied by the auxiliary voltage source (V_1), will be equal to the copper loss in the two transformers

and the voltage V_1 will be double the impedance voltage drop of either of them. The power taken from the L.T. supply will continue to be the combined core loss of the two transformers.
On circulating the full load current through a transformer in the manner described above for a sufficient period, the steady temperature can be detected while at the same time the drawn power from the supply is only equal to the total losses in the two transformers.
Also, measurements of the voltage, powers and currents drawn from the sources make it possible to calculate the parameters of the two transformers.

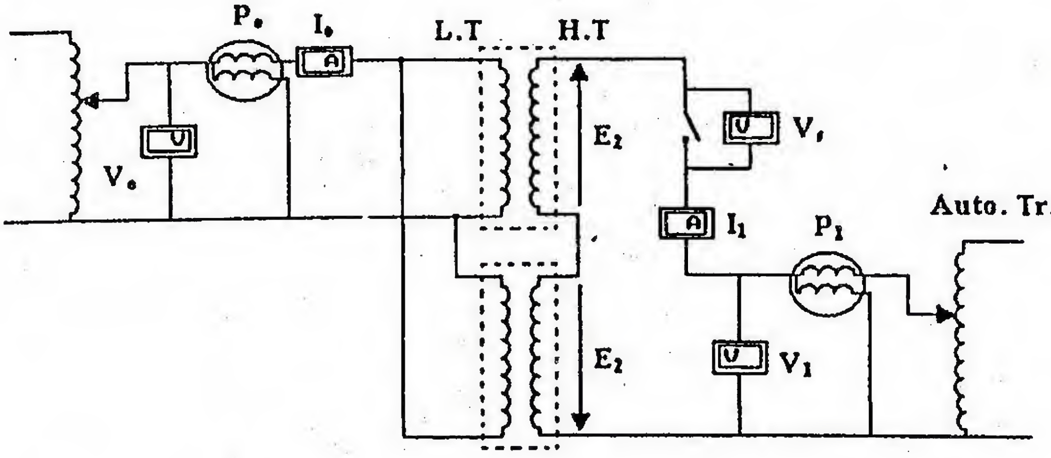


Fig. 2

B-Experiment:
Object: Determination of the parameters of a single phase transformer by the back to back test.

Preliminary: Take complete particulars of the two transformers under tests.

Connection diagram: In accordance with the above mentioned theory, the connection diagram together with the measuring instruments are shown in Fig. 2.
The switch "S" together with the voltmeter V_s across it is used to make sure that the two high voltage secondaries are connected in opposition.

Procedure:

1-Connected the circuit as shown in Fig. 2 keeping switch "S" opened.

2-Apply normal voltage to the L.T. windings making V_1 (Auxiliary transformer voltage) equal zero. Take the reading of V_s.

If $V_s = 0$, the connection of the H.T. windings is correct i.e. in opposition. If V_s has a value rather than zero one of the windings must be reversed. With correct connection, close "S".

3-With $V_1 = 0$ take reading of V_o, P_o and I_o.

4-Increase V_1 in steps and take reading of I_1, P_1 for each value of V_1.

Calculation of the losses:

$$\text{Iron losses} = \frac{P_o}{2} - \frac{I_o r_1^2}{4} \approx \frac{P_o}{2} \quad \frac{P_o}{2} - \frac{I_o r_1^2}{4} = \frac{P_o}{2}$$

$$\text{Copper losses} = \frac{P_1}{2}$$

The parameters can be calculated as follows:

$$\frac{P_o}{2} = \frac{I_o}{2} V_o \cos\phi_o \qquad \cos\phi_o = \frac{P_o}{I_o V_o}$$

$$\frac{2V_o}{I_o} \angle -\phi_o = Z_o \text{ of the magnetizing arm.}$$

$$P_1 = 2I_1^2 r_1 \qquad r_1 = \frac{P_1}{2I_1^2}$$

$$\frac{P_1}{2} = I_1 \frac{V_1}{2} \cos\phi_{s.c.} \qquad \cos\phi_{s.c} = \frac{P_1}{I_1 V_1}$$

$$Z_{s.c.} = \frac{V_1}{2I_1} \angle -\phi_{s.c}$$

Required:

1-Draw the losses against the circulating current.

2-Deduction of the equivalent circuit of the transformer referred to the primary.

3-The efficiency curves at unity and 0.8 P.F. lagging for different loading.

4-The regulation curves at P.Fs. unity, 0.8 lagging and 0.8 leading for different loadings.

(II)

High Voltage Experiments

(1)
Testing of Transformer Oil

The transformer oil is the final product of refining a certain oil fraction. It is used in different kinds of electrical apparatus such as transformers, switches, circuit breakers and others. In electric apparatus, insulating oil fulfils a number of important functions.

1. Insulation for the apparatus.
2. Cooling of the winding and magnetic circuit, which emit heat due to loss.
3. Cooling of arc between the separating contacts of circuit breaker during tripping for rapidly arc extinction.

The reliable operation of a power system largely depends on the grade and state of the oil used in its equipment. Therefore, for the oil to be used successfully, its properties must fully comply with the oil standards. The oil standards give the minimum accepted values for the oil properties, when measured by specified tests. The properties of the oil may be classified as:

1-Electric strength.

2-Viscosity.

3-Flash point

4-Freezing point.

5-Transparency and ash contents.

As the oil serves as an insulating material, the electric strength is a very important characteristic, which may be estimated by performing breakdown test to oil sample.

Sphere-Sphere Breakdown test:

The test is usually carried out with apparatus specially designed for the purpose, Fig. 1. The oil to be tested is placed in the oil container (1) with the sphere gaps (2) adjusted to the required distance. The high voltage is applied to the electrodes from the secondary of a high voltage transformer (3), the primary of which is supplied through a regulating transformer (4). The voltmeter (5) is adjusted to read the voltage on the high voltage side in R.M.S values.

In order to protect the circuit from short-circuit currents following oil breakdown an automatic circuit breaker (7) is adjusted to interrupt the circuit from the supply side at breakdown condition. A grounded metallic cage covers the oil container together with the high voltage electrodes in order to protect the operator from being exposed to stressed sphere. For safety purposes the cage is equipped with a double switch (8) which makes it possible to connect circuit only when it is closed. A lamp (6) indicates that the tester is ready for testing i.e. switch (9) and circuit breaker (7) are closed.

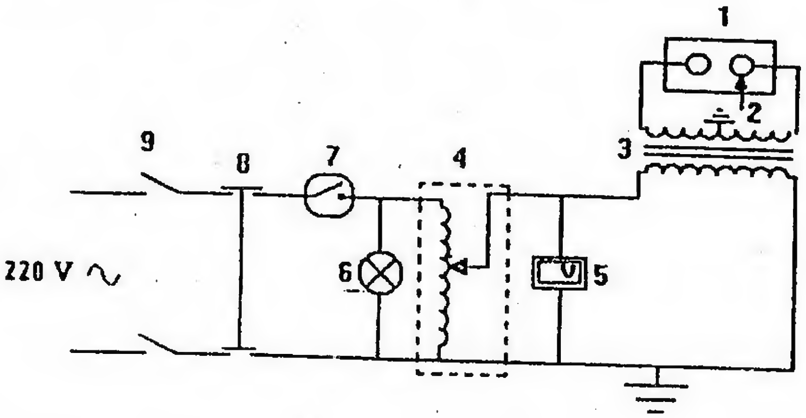


Fig. 1: Transformer oil tester

Procedures:

1-The main switch (9) should be in the open position.

2-The slide indicator of the regulating transformer should be in the zero position.

3-The circuit breaker (7) should be in the open position.

4-The sphere gap (2) is adjusted by a means of a feeler gauge at the desired distance. The container is filled with the oil to be tested. Then the container is placed in its position on top of two high voltage bushings inside covering cage and the cover is closed.

5-Close the main switch (9) and then the circuit breaker (7), which will light up the signal lamp (6).

6-Increase the voltage slowly at a rate of 1 kV/sec and watch the reading of the voltmeter until breakdown occurs. At breakdown, the circuit breaker (7) will interrupt the circuit and the voltmeter will drop to zero.

7-The maximum reading by the voltmeter indicates the breakdown voltage of the oil.

8-The test should be repeated at least five times, to determine a faithful value of the breakdown voltage.

9-Repeat the procedure for different gap spacings between spheres and tabulate the breakdown voltage against the spacing between the spheres.

10-For comparison purpose, repeat the test for air at different gap spacings.

11-Compare the dielectric strength of oil against that of air. The dielectric strength is determined by the maximum field strength at breakdown condition. The maximum strength is expressed in Appendix 1.

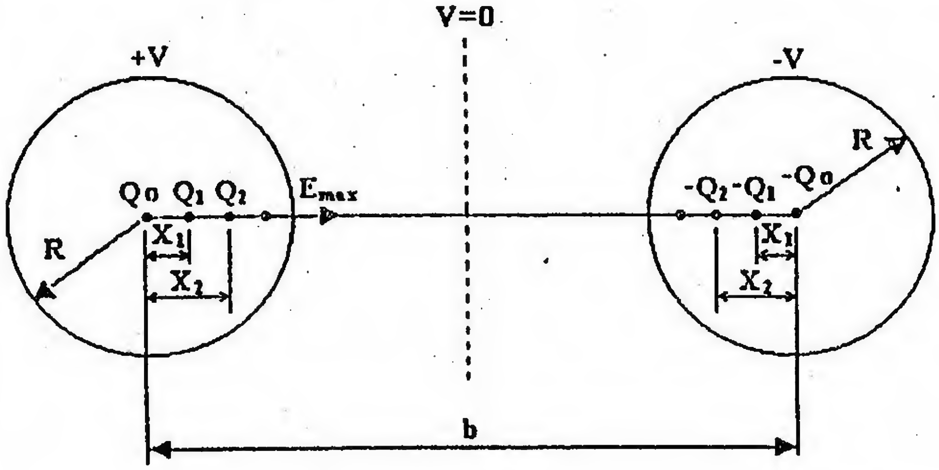
Sphere-Grounded Sphere Breakdown Test:

In the following test the sphere-gap container is removed from the tester and one of the high voltage bushing shown in Fig. 1 is connected to one side of the sphere gap. The other side of the sphere gap is grounded. Care must be taken to isolate sufficiently the high voltage terminal from the covering cage. The test is now conducted exactly as described before in steps 1 through 10 except that the voltmeter readings must be divided by 2 (i.e. for example by breakdown at 50 kV voltmeter reading, the test voltage to earth is only 25 kV). Why?

Comment on the results obtained against those recorded in sphere-sphere breakdown tests.

Appendix – I

Electric Stress in Sphere-Sphere Gap:



The electric stress in sphere-sphere gap is determined using the successive imaging technique [1] where the surface charge on each sphere is represented by a set of discrete image charges Q_0, Q_1, Q_2...

The image charges are expressed as:

$$Q_n = Q_{n-1}\frac{R}{b - x_{n-1}} \quad , n = 1, 2, 3, \ldots..$$

where their locations $x_n = \dfrac{R^2}{b - x_{n-1}}$

R = Sphere radius

b = Sphere-Sphere spacing

The first image charge Q_0 is equal to $4\pi\varepsilon_0\varepsilon_r RV$ and located at $x_0 = 0$.

V = is the voltage applied to each sphere at breakdown.

ε_r = Relative permittivity of the medium between spheres.

The maximum field strength E_{max} at sphere surface is given by:

$$E_{max} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\left(\sum_{n=0}^{\infty}\frac{Q_n}{(R-x_n)^2}+\sum_{n=0}^{\infty}\frac{Q_n}{(b-R-x_n)^2}\right)$$

<u>Reference:</u>

[1] E. Kuffel and W. Zangel, "High Voltage Engineering", Pergamon Press, 1984.

(2)
High Voltage Measurements

Main Object

1. To be acquainted with the high voltage testing equipment and measuring devices
2. To study the protection and safety arrangements used in the test.
3. To obtain the characteristics of sphere gaps and to compare them with standard tables.
4. To obtain the flashover voltage for suspension insulators.
5. To demonstrate the function of horn gaps.

A-Testing of a String of Suspension Insulators

Test Set-Up:

Give a description of the HV 50-cps testing circuit and equipment present in the laboratory. Explain the methods of high voltage measurement and the arrangement used for circuit protection and for safety of personal. What precautions are necessary?

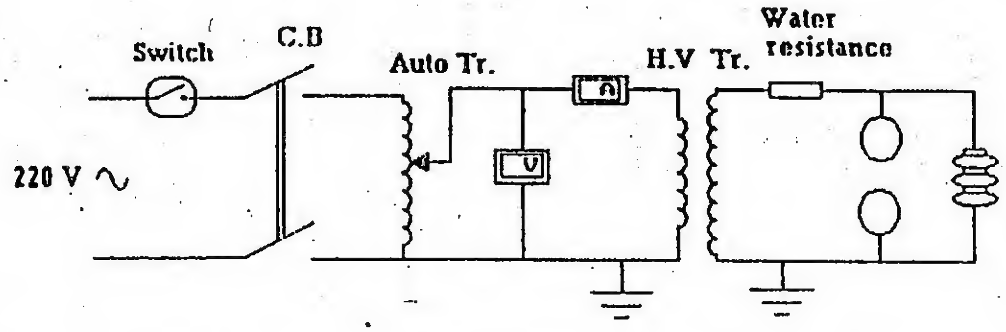


Fig. 1: H.V testing circuit for a string of suspension insulators.

1- Dry and wet flashover voltage for a string of suspension insulators:

1- Connect the insulator units as shown in Fig. 1.

2- Measure the dry flashover voltage and leakage current for insulator strings of 1, 2 and 3 units.

3- Repeat step (2) under wet conditions simulated by artificial rain.

Results:

Tabulate the dry and wet flashover voltages for the units of the insulator strings. Hence, deduce the voltage distribution along the insulator strings as well as the string efficiency.

Discussions:

Explain why the dry flashover voltage of an insulator string is less than n times the dry flashover voltage of each insulator unit, where n is the number of units of the insulator string.

2- How the potential distribution over a string of suspension insulators is improved:

Theory:

Figure 2 shows the equivalent circuit of a string of suspension insulators.

Let: C = Capacitance of each unit

And m = capacitance to ground (tower frame) / capacitance of each unit

Then mC = capacitance to ground

With the notation indicated in Fig. 2, we can find that

$E_2 = E_1 (1 + m)$

$E_3 = E_1 (1 + 3m + m^2)$

$E_4 = E_1 (1 + 6m + 5m^2 + m^3)$

Also we have $E = E_1 + E_2 + E_3 + E_4$

Where E is the total voltage across the string.

$E_1, E_2, \ldots. E_4$ are the voltage across the subsequent units of the string starting from the tower frame.

Test Set-Up

Capacitors (C) connected in series are used to represent units of the suspension insulator string. Other capacitors are used to represent capacitances (mC) between the string and the ground.

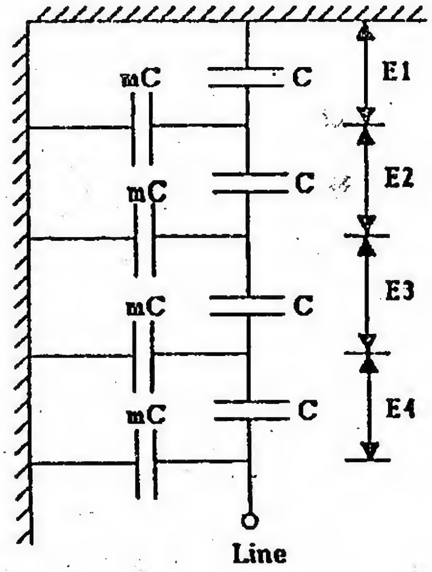


Fig. 2: Potential distribution over a string.

Procedure

1- With reference to Fig. 2 which represents the string and its earth capacitances;

Take capacitance of each unit $C = 4.0\ \mu F$

And capacitance to ground $mC = 0.25\ \mu F$

2- Connect a 110 V ac supply across the string. Measure the total voltage across each unit using a vacuum voltmeter.

3- Repeat the above procedure for various values for mC and plot curves for the voltage distribution across the insulator string for each value of mC.

4- Connect capacitors to represent the guard ring, taking mC = 0.25 μF. Adjust the values of capacitors representing the ring to achieve uniform distribution of potentials along the strings.

5- Compare your results obtained experimentally with those calculated.

B-Sphere gap Characteristics

Two sets of sphere gaps of diameters 6.25, 12.5 and 25 cms are arranged for testing.

Procedure:

1) Measure the limiting water resistance and make sure that its value is not less than 1 MΩ. Make sure that the resistance-connected electrodes are well impressed in water to avoid its heating.

2) Fix the pair of sphere to be tested in position and adjust the zero setting of the gap. Care must be taken not to bump the spheres together.

3) Start with spacing of 0.5 cm and increase the voltage gradually at a constant rate (5 kV/sec) as possible as you can until breakdown occurs. Take the corresponding reading of the panel voltmeter

4) Repeat the test for various spacings of 0.5, 1, 2, 3 and 4 cm

5) Record the atmospheric conditions of pressure P (torr) and temperature t c° during the test.

6) Correct the measured breakdown voltage values for normal pressure and temperature (N.T.P) by division with air density $\delta = \frac{0.392P}{273 + t}$

7) Repeat the above procedure as whole for other sphere gaps.

Results:

Plot for each sphere gap.

(i) the sphere gap characteristic curve, i.e. the breakdown voltage verus the spacing S between the spheres at N.T.P.

(ii) The characteristic curve obtained from the attached standard Table 1.

(iii) The characteristic curve as calculated from the empirical equation

$$V_{\dots} = 17.62\left(1+\frac{0.75}{D}\frac{S}{Df}\right)kV$$

Where D and S are the diameter and spacing of spheres respectively, and f is a factor depending on S/D (see Table 2).

Discussions:

Give comments on the various characteristics obtained for each sphere gap.

C-Arc on the Horn Gap

Connect the horn gap to the HV testing circuit of Fig. 1. Increase the voltage until breakdown occurs. Observe the behavior of the arc and comment on the use of horn gap as a protection device against over-voltages.

Table 1: Breakdown voltage of sphere gap in air at 20°C and 760 mm Hg for power frequency (one sphere grounded).

Spacing S (cm)	Diam of Sphere (cms)				
	5.0	6.25	12.5	25.0	50.0
0.5	17.3	17.1	16.7	-	-
1.0	32.0	31.9	31.5	-	-
1.5	45.7	45.9	45.6	45.0	-
2.0	57.4	58.2	59.2	59.0	58.0
2.5	67.2	69.6	72.0	72.0	-
3.0	75.4	79.1	85.2	86.0	-
4.0	88.4	94.8	109.0	112.0	112.0
5.0	98.0	107.0	129.0	137.0	137.0
6.0	-	116.0	146.0	161.0	164.0
7.0	-	-	162.0	184.0	-
8.0	-	-	174.0	205.0	214.0
9.0	-	-	186.0	225.0	238.0
10.0	-	-	196.0	243.0	-
12.0	-	-	212.0	275.0	208.0
14.0	-	-	-	302.0	352.0
16.0	-	-	-	352.0	392.0
18.0	-	-	-	345.0	428.0
20.0	-	-	-	363.0	461.0

Table 2: Factor f for different values of S/D

S/D	f
0.05	1.035
0.15	1.105
0.25	1.186
0.50	1.410

(3)
Electrical Corona
Part I. Corona Phenomena

Object:
To study the following aspects of corona phenomena:

1) Corona Current
When corona discharge takes place at the surface of a conducts, electrons are accelerated by the high electric field. They aquire energy high enough to produce ionization by collision with the gas molecules, thus on electron avalanche is produced. The motion of electrons and ions in the electric field correspond to corona current.

The positive ions produced by the ionization collisions distort the field and ultimately chock the discharge.

When the positive ions are swept away from the vicinity of the conductor, the original high value of the electric field will be reached again and the corona discharge will take the form of a new avalanche. Each of these avalanches contributes to high pulse pattern in the corona current.

2) Types of Corona Discharge
It is seen that corona current can take the form of repetitive pulses. With negative polarity of the applied voltage, these pulses are known as "Trichel pulses while with positive polarity as "positive streamers"

The positive corona pulses, as a result of having different mechanism, are of much bigger amplitude and charge than the negative corona pulses. The repetition rate of negative pulses is of the order of $10^3 - 10^6$ pulses/sec, while the repition rate of positive corona pulses is of the order of 100 – 1000 pulses/sec.

With alternating applied voltages, the corona discharge on each half cycle of the voltage wave will be similar to that with direct applied voltage of the same polarity, although the space charge from the preceding half-cycle may modify the discharge.

3) Corona Power Loss

A phenomenon of great practical importance when corona appears on high voltage transmission lines is the accompanying loss of power. This energy loss is that required to complete the different processes in the discharge.

4) Radio Interference due to Corona

Pulses in corona current, which is random in nature, have a continuous frequency spectrum. This means that corona when present in a HV. circuit, is equivalent to a radio transmitter transmitting signals at all frequencies which include the hf range. It will thus cause a noise in hearing by radio receivers. Positive corona was found to produce much higher interference as compared with negative corona.

Procedure:

1) Connect the oscilloscope in such away as to see the wave form of the corona current and notice the difference between the positive and negative half-cycles of the current: Fig. 1.
2) Estimate the frequency of corona pulses during the positive half cycle with that during the negative half cycle.
3) Connect the oscilloscope as in diagram, Fig. 2, for measuring the corona loss, and prove that the lissajous figure shown on the screen of the C.R.O. is proportional to the corona loss.

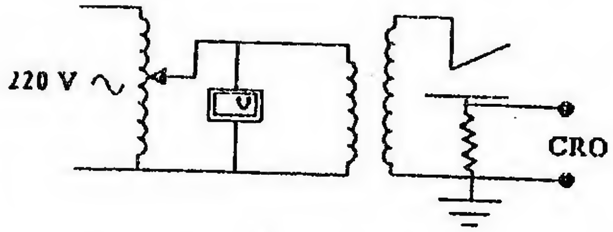


Fig. 1:

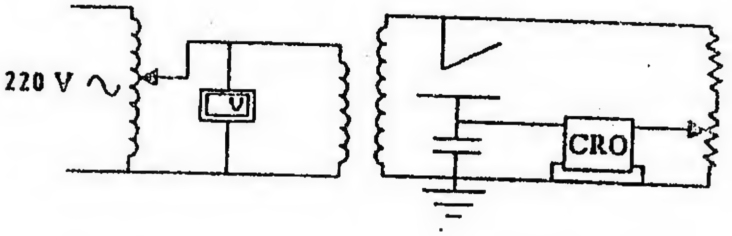


Fig. 2:

Electrical Corona
Part II. Corona Power Loss on Single and Bundled H.V. Transmission lines

Corona may appear on the H.V. wires and located around clamps and metal fittings due to concentration of high electric fields.

Methods of reducing corona on H.V. lines

Corona on insulator strings can be minimized by linearizing the voltage distribution across them sharp and avoiding edges and protrusions in the whole system.

Corona on the wire surface. Can be limited by increasing the diameters or the spacing of the conductors. The spacing has an upper limit set up by the mechanical design of the supporting tower. The diameter of solid conductors cannot also be increased indefinitely as limited by its weight and cost. Solid conductors has then to be replaced by another suitable form; e,g.

i) Hollow conductors: which increases the overall diameter for the same weight. It is expensive and difficult to manufacture.

ii) Bundled conductors: i.e. to split the conductor to a number of smaller diameter conductors separated by an adequate distance (about 40 cm) and kept at the same potential. The number of conductors in a bundle is usually 2,3 or 4. This increases the "effective" diameter of the conductor and thus reduces the voltage gradient at their surfaces and limits corona. This method is commonly used for EHV lines.

Experiment:

It is required to:

i) Measure the effect of bundling in increasing the onset voltage of corona.

ii) Measure the corona loss of a conductor-to- ground arrangement when the conductor is single and when it is a bundle.

Procedure:

1) Connect the high voltage circuit without test conductors.
2) Using a wattmeter in the primary circuit, measure the input power to the H.V. transformer at different voltages as shown in Fig. 3.
3) With the test conductors connected, measure the disruptive and visual corona onset voltage.
4) Also, measure the power input to the H.V. transformer at different voltages.

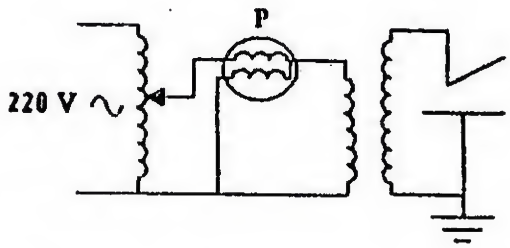


Fig. 3:

5) With single conductor, Plot the corona loss (the difference between the wattmeter readings in steps 4 and 2 above) against the conductor voltage and check values with those you calculate using peek's formula and estimate the surface factor of the conductor.

Peek's formula:

$$P = (390/\delta)(f + 25)(\sqrt{r/D})(V - V_o)^2\ 10^{-5}\ \text{kW/mile}$$

where f = frequency in cycles per sec.

r = conductor radius

D = conductor spacing

V = applied voltage to neutral

V_o = disruptive corona voltage – to – neutral.

δ = relative air density = $\frac{3.92\ P}{t + 273}$

with P is the barometric pressure in mmHg and t is the laboratory temperature in C°.

(6) Plot the measured corona loss with single conductor against the applied voltage. Compare the loss values with those obtained for bundle conductor.

(4)
Corona Current Distribution Underneath High voltage Transmission Lines

Objective:

To measure the corona current density distribution underneath a laboratory model of a high voltage transmission line for different values of applied voltage, different conductor diameters and heights above the ground plane.

Introduction:

With the increase of the voltage across a uniform-field gap, breakdown of the gap takes place in the form of a spark without any preliminary discharges. For non-uniform field gaps, as the case of high voltage transmission line an increase in voltage will first cause a discharge in the surrounding air to appear at a point with highest electric field intensity, namely at sharp points on transmission lines. This form of discharge is called a corona discharge and can be observed as a bluish luminescence; a hissing noise, and the air surrounding the corona region becomes converted into ozone. This phenomenon is of particular importance in HV engineering where non-uniform fields are unavoidable. It in responsible for considerable power losses from HV transmission lines and often leads to deterioration of the insulation by the combined action of the discharge ions bombarding the surface and the action of the chemical compounds such as ozone (O_3) that are formed by discharge. It may give rise to interference in communications systems. On the other hand, it has various industrial applications such as high speed printing devices, electrostatic precipitators, paint sprayers, Geiger counters, etc.

It is quite clear that the corona current decreases with the increase of the transmission line height for the same applied voltage and the same diameter of the line. The larger the transmission - line height the more is the decease of the electric field along the flux lines, where the corona ions are convecting between the high voltage line and the collecting plate (earth), with a subsequent decrease of the corona current.

It is well known that increasing the wire diameter causes the corona onset voltage to increase with a subsequent decease of corona current for the same applied voltage and the same conductor height.

The current density over the collecting plate (earth) is not uniform and assumes maximum value directly opposite to the high voltage conductor.

Experimental Set-up:

A schematic diagram of the experimental set-up is shown in figure(1),which consists of the following elements:

A regulating transformer (T1), whose input is 220 volts ac. The automatic switch (S) to connect or isolate (disconnect) the supply to the circuit. An ac voltmeter (V) to record the input voltage. To control the input voltage to the high voltage transformer, the output of the regulating transformer is connected to two variac transformers (T2, T3) to get fine and coarse control of the input voltage. The HV transformer (T4), is to step up the voltage to the desired value (0-100kV). A half wave HV rectifier circuit (D1, D2, R1, R2, C1, C2) is composed of two diodes (20 mA, 140kV PIV) and two smoothing capacitors (1nF, 140kV), and two resistors (100KΩ). The high voltage value is measured as equal to the voltage drop across the 280MΩ resistor (R3), which can be calculated by measuring the current passing

through it using a sensitive micro-ammeter (M). The water resistance R_w (0.5 MΩ) is to limit the current in case of a flash happens.

The transmission-line conductor is smooth copper wire with different diameters and is hanged horizontally over the collecting plate (P) representing the ground plate underneath the line. The corona current can be measured using a galvanometer G with accuracy of 10^{-8} A.

Experimental Technique:

To measure the current distribution over the collecting plate (earth), the plate is divided into 42 strips each of area $1.0 \times 0.04\,m$. The strips are arranged such that there is 1 mm separation between adjacent strips. The setup is made to ensure that all strips are grounded except the strip at which the current is to be measured. The latter is grounded through the galvanometer G. The sum of the currents of the strips is equal to the total corona current. The strip current density is simply obtained by dividing the strip current by its area. Measuring the current density for all the strips determines the lateral distribution of the current density over the collecting plate.

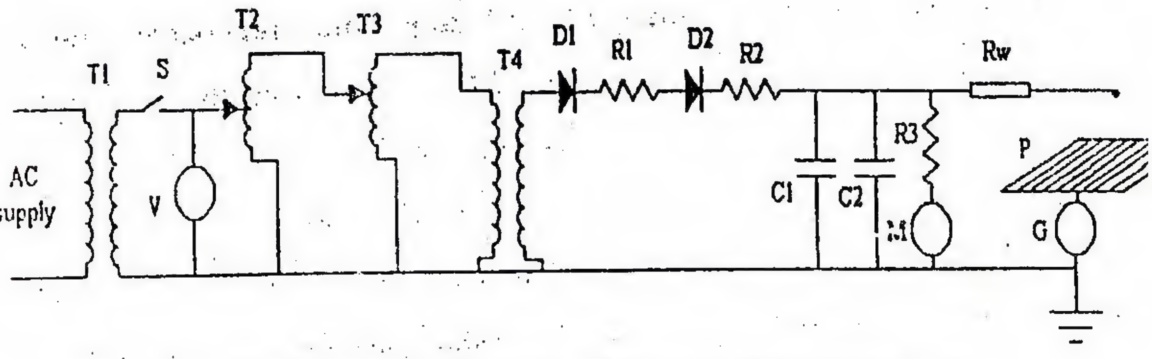


Fig.(1): Schematic diagram of the experimental set-up.

Results:

1-Plot for the same applied voltage and the same conductor diameter, the current density distribution along the collecting plate for different conductor heights.

2-Plot for the same applied voltage and the same conductor height, the current density distribution along the collecting plate for different conductor diameters.

3-Plot for the same conductor height and diameter, the current density distribution along the collecting plate for different applied voltages.

Discussion:

Give comments on the effects of the applied voltage, the diameter and the height of the conductor on the corona current distribution underneath the conductor.

(5)
Measurement of Earth Resistance

Objective:

To determine the earth resistance and subsequently to determine the earth resistivity using the three/four-electrode methods

Introduction:

Earth conduction problems are encountered in communication and power system engineering in connection with investigations of earth resistivity, grounding, corrosion, inductive interference and lighting disturbances. The earth is the terminal for lighting disturbances and when charge is suddenly transferred to earth or to a grounded object, it seeks to spread outward until neutralized by ambient charge level of the whole earth mass. The capability of the earth to accept the discharge energy depends on the resistivity of the soil at the particular location and the effectiveness of the electrical connection to the earth.

The principle characteristics affecting soil resistivity are the following:

1-Soil type	2-Salt content
3-Moisture content	4-Temperature
5-Grain size	6-Compactness

Typical earth resistivity range from 1 to 10000 ohm. meter.

Measuring Earth Resistivity

The most reliable method of measuring the earth resistivity is the three-electrode method. Three electrodes are used, figure (1), E is a hemisphere electrode whose resistance can be easily related to the earth resistivity as:

$$R_e = \frac{\rho_e}{2\pi r_o} \qquad (1)$$

where ρ_e=earth resistivity, r_o=hemisphere radius and R_e=earth resistance. P (potential electrode) and C (current electrode) are auxiliary rods driven into the earth.

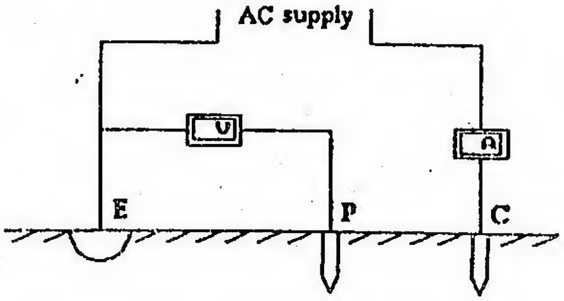


Fig. 1:

The "four-electrode method" is frequently used to obtain the earth resistivity. Four electrodes are used, figure (2). Here, the current is passed between two hemisphere electrodes (E and C electrodes) and the potential is measured between two intermediate potential electrodes (P electrodes). In most cases, the resistivity of a considerable volume of earth is required, so that the electrodes must be a good distance apart. The dimensions of the electrodes therefore will be small compared to the distance between them, so that the current distribution is practically the same as when the electrodes are considered as points.

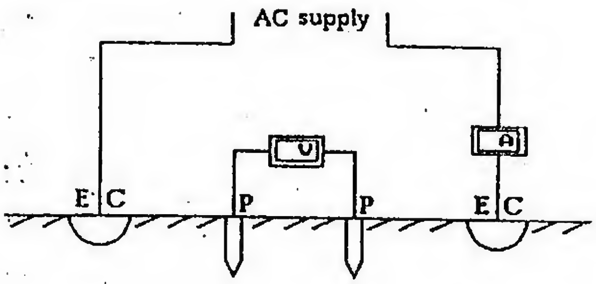


Fig. 2:

The object of the method (three-electrode or four electrodes) is to determine the earth resistance and subsequently to determine the earth resistivity ρ_e.

A-The "three-electrode" method

First approach (Fall of potential method)

A known value of current is circulated between E-C causing a potential drop to be created between E-P. The earth resistance is the result of dividing the potential drop by the current. As P moves away from E, the resistance would vary in the manner shown in figure (3). The true resistance of the electrode E to earth is measured with P being at an intermediate distance from E, i.e. on the flat part of the characteristics, figure (3). If the distance to PE can be measured from the centre of the E electrode, it has been shown that the true resistance is obtained when the distance to P equals 61.8% of the distance to C electrode.

The last rise in the resistance near the electrode C is due to the resistance to earth of C itself and may thus be used to measure that resistance.

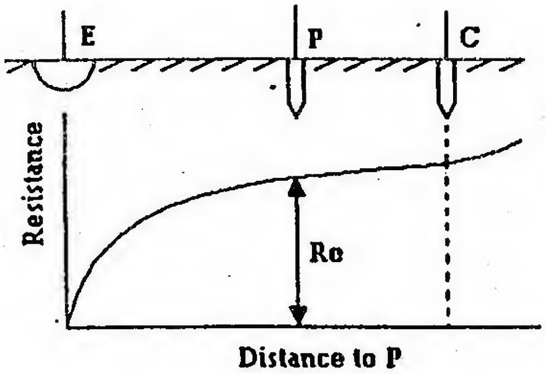


Fig. 3:

<u>Second approch (4-potential method)</u>

In this method, measurements are made with P at four chosen distance from the E electrode, and formulas are given from which the true resistance can be calculated. These formulas are of the following form

$$R_e = \alpha R_1 + \beta R_2 + \gamma R_3 + \delta R_4 \qquad (2)$$

where R_1, R_2, R_3, R_4 are the resistances corresponding to the four chosen distance from the E electrode and the values of the coefficients for various combinations of distance are given in the Table (1).

The resistivity of earth is :

$$\rho_e = 2\pi r_o R_e \qquad (3)$$

when R_e is in ohms and r_o in meter, Equation (3) gives the earth resistivity in ohms. meter.

Table (1):
Coefficients for various distances where distance to P as a fraction of distance to C.

EP/EC				α	β	γ	δ
0.2	0.4	0.6	0.8	-0.1187	-0.4667	+1.9816	-0.3961
0.4	0.5	0.6	0.8	-2.6108	+4.050[illegible]	-0.1626	-0.2774
0.4	0.5	0.6	0.7	-1.8871	+1.1[illegible]8	+3.6837	-1.9114
0.5	0.6	0.7	0.8	-6.5225	+13[illegible]816	-6.8803	+0.7210

B-The four-electrode method

Let a current I enters the ground at a point electrode and let the other current electrode be sufficiently remote so that its presence may be neglected. The current is then radial about the surface point electrode. Imagine a hemisphercical surface with center at the electrode and radius r. The area of this surface is $2\pi r^2$, and the radial current density in the ground at the distance r is then $J=\dfrac{I}{2\pi r^2}$. If ρ_e is the earth resistivity, the electric field intensity in the gound in the radial direction at the distance r is

$$E(r)=J\rho_e$$

or

$$E(r)=\frac{I\rho_e}{2\pi r^2} \qquad (4)$$

The potential at the distance r from the electrode is the integral of electric force between r and an infinitely remote point.

$$V=\int_r^{\infty} E(r)\,dr=\frac{I\rho_e}{2\pi r} \qquad (5)$$

The ratio of potential to current or the resistance of the electrode at the point under consideration (sometimes donoted the mutual resistance of the electrode and the point under consideration), is then:

$$R(r)=\frac{\rho_o}{2\pi r} \qquad (6)$$

Assume next two electrodes, 1 and 2 on the earth's surface. Let a current enters the earth at 1 and leaves at 2, and consider the resistances with a point 3 on the surface, as indicated in figure (4).

The resultant resistance is then the difference between $R(r_{13})$ and $R(r_{23})$.

In a differential notation:

$$R_{(1-2)3} = R_{13} - R_{23} = \frac{\rho_e}{2\pi}\left(\frac{1}{r_{13}} - \frac{1}{r_{23}}\right) \tag{7}$$

where r_{13} and r_{23} are the distances between points 1 and 3 and points 2 and 3, and the subscript (1-2)3 or R denotes that the current path is between points 1 and 2 while the potential is taken at 3.

With an additional point , 4, on the surface as shown in figure (5), it follows that the resistance of a circuit between 1 and 2 with a circuit between 3 and 4 is :

$$\begin{aligned} R_{(1-2)(3-4)} &= R_{13} - R_{23} - R_{14} + R_{24} \\ &= \frac{\rho_e}{2\pi}\left(\frac{1}{r_{13}} - \frac{1}{r_{23}} - \frac{1}{r_{14}} + \frac{1}{r_{24}}\right) \end{aligned} \tag{8}$$

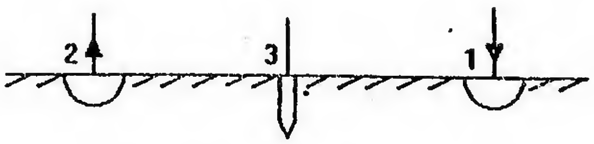


Fig. 4

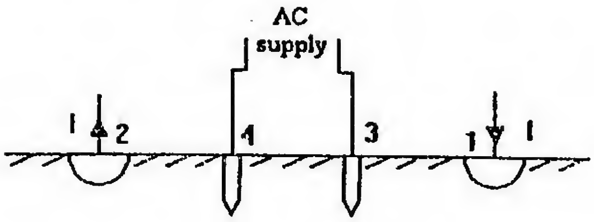


Fig. 5

From the above formulas, the distances r were between points on the surface of the earth. Consider the four electrodes on a straight line at equal spacing d , 1 and 2 being the outer electrodes. Then $r_{13} = r_{24} = d$, $r_{14} = r_{23} = 2d$.

The resistance is then:

$$R_{(1-2)(3-4)} = \frac{\rho_e}{2\pi}\left(\frac{2}{d} - \frac{1}{d}\right) = \frac{\rho_e}{2\pi d} \qquad (9)$$

The resistivity of earth is :

$$\rho_e = 2\pi d R_{(1-2)(3-4)} \qquad (10)$$

when R (1-2)(3-4) in ohms and d in meters, equation (8) gives the earth resisitivity in meter ohms.

Experiment:

Given two hemispheres electrodes (6.25 cm in diameter) and two rods (1 cm in diameter) from copper, and a muddy sample of the space outside the laboratory.

1-Using the three-electrode method, plot the complete earth resistance curve and determine the resistance to earth of the rod.

2-Determine the earth resistivity of the soil using the measured earth resistances in step (1) and equation (1):

3-Determine also the earth resistivity using the four-electrode method, equation (10).

4-Check the results you obtained in step (2) against the four-potential method being another approach for earth resistivity measurements.

5-Comment on the obtained results.

Note: The source to be used in earthing measurememts should be the ac type to avoid the effect of back emf developed within the earth volume due to electrolytic action (polarization at the earthing electrodes).

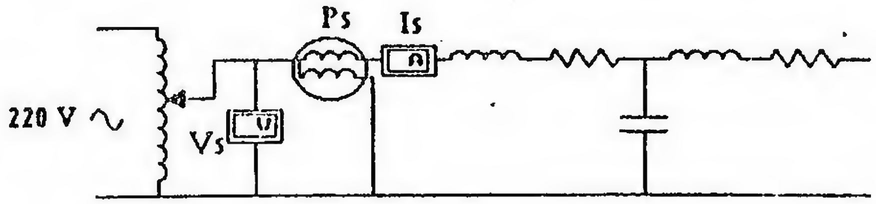
(6)
Performance of Transmission Lines

Object:

To obtain the transmission-line constant experimentally and to study the performance of the T.L. with and without synchronous condenser.

A- Symmetrical T.L.

1-No load test with receiving end open



Vary V_s by means of autotransformer and take reading of V_s, I_s, P_s

$V_s = A\ V_r + B\ I_r$

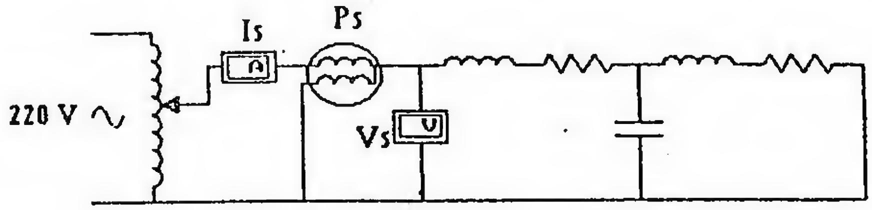
$I_s = C\ V_r + D\ I_r$

$I_r = o$

$$\frac{V_s}{I_s} = \frac{A}{C} = Z_{o.c} \angle \phi_{o.c} \qquad (1)$$

$P_s = V_s\ I_s \cos \emptyset_{o.c}$

2-Short circuit test at receiving end



Vary V_s and take reading of V_s, I_s, W_s

$V_s = A\,V_r + B\,I_r$

$I_s = C\,V_r + D\,I_r$

$V_r = o$

$$\frac{V_s}{I_s} = \frac{A}{C} = Z_{s.c}\angle\phi_{s.c} \qquad (2)$$

$P_s = V_s I_s \cos \varnothing_{s.c}$

For symmetrical T.L. $A = D$ (3)

$AD - BC = 1$ (4)

$A^2 - BC = 1$

$$\frac{Z_{o.c}\angle\phi_{o.c}}{Z_{s.c}\angle\phi_{s.c}} = \frac{AD}{CB} = \frac{A^2}{A^2-1}$$

$$\frac{Z_{o.c}\angle\phi_{o.c}}{Z_{o.c}\angle\phi_{o.c} - Z_{s.c}\angle\phi_{s.c}} = \frac{A^2}{A^2-A^2+1} = A^2$$

$$A = \sqrt{\frac{Z_{o.c}\angle\phi_{o.c}}{Z_{o.c}\angle\phi_{o.c} - Z_{s.c}\angle\phi_{s.c}}} = D$$

From equation (1) $\quad C = \dfrac{A}{Z_{o.c}\angle\phi_{o.c}} = \sqrt{\dfrac{1}{Z_{o.c}\angle\phi_{o.c}(Z_{o.c}\angle\phi_{o.c} - Z_{s.c}\angle\phi_{s.c})}}$

From equation (2) $\quad B = D\,Z_{s.c}\angle\phi_{s.c} = Z_{s.c}\angle\phi_{s.c}\sqrt{\dfrac{Z_{o.c}\angle\phi_{o.c}}{Z_{o.c}\angle\phi_{o.c} - Z_{s.c}\angle\phi_{s.c}}}$

B- Unsymmetrical T.L.

The first and the second tests are the same, i.e

$$Z_{soc} \angle \phi_{soc} = \frac{A}{C} \tag{5}$$

$$Z_{ssc} \angle \phi_{ssc} = \frac{B}{D} \tag{6}$$

3- Open circuit test with sending end open

$V_s = A\ V_r + B\ I_r$

$I_s = C\ V_r + D\ I_r$

$D\ V_s = A\ D\ V_r + B\ D\ I_r$

$B\ I_s = C\ B\ V_r + B\ D\ I_r$

$D\ V_s - B\ I_s = V_r$

$C\ V_s = A\ C\ V_r + B\ C\ I_r$

$A\ I_s = A\ C\ V_r + A\ D\ I_r$

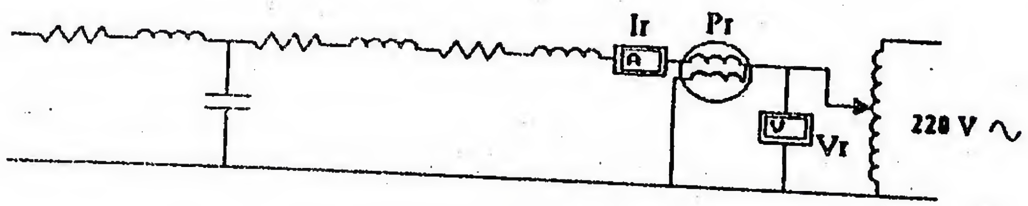
$A\ I_s - C\ V_s + I_r$

I_s and I_r are reversed in direction

$V_r = D\ V_s + B\ I_s$

$I_r = C\ V_s + A\ I_s$

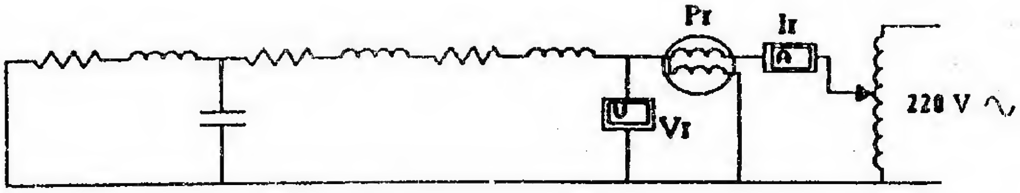
With sending end open $I_s = 0$



$$\frac{V_r}{I_r} = \frac{D}{C} = Z_{roc} \angle \phi_{roc} \tag{7}$$

4-Short circuit test at receiving end

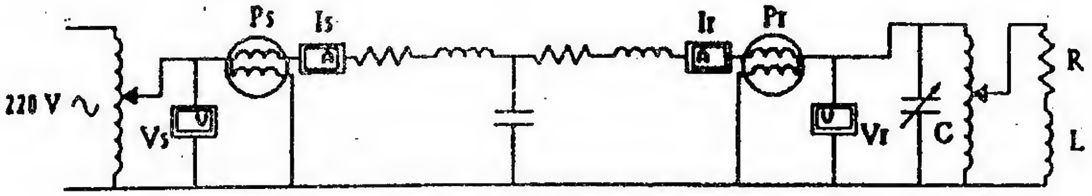
$V_s = 0$



$$\frac{V_r}{I_r} = \frac{B}{A} = Z_{r.s.c}\angle\phi_{r.s.c} \tag{8}$$

With the aid of equations 4 through 8, the constants A, B, C and D are determined.

C-Load test



a- Maintain V_s constant and vary V_r, then take the readings of V_r, I_r, P_r, P_s and I_s.

Plot V_r, I_r, P_r and I_s versus P_s.

b- Maintain V_r constant and vary V_s, then take readings of V_s, I_s, P_s, I_r and P_r.

Plot V_s, I_s, P_s and I_r versus P_r.

c- Maintain V_s constant and V_r constant and vary I_r by inserting capacitance in parallel at the receiving end, then take readings of V_r, I_r, P_s, P_r and C.

Plot I_s, P_s, I_r and P_r versus C.

Note : Use the power circle diagram to check up the obtained results.

(7)
Constants of Transmission Lines with Stranded Conductors

Introduction:

An overhead transmission line is characterized by four constants; namely, the resistance, inductance, capacitance, and conductance.

When current flows in an electric circuit, some of the circuit properties are explained by the produced magnetic and electric fields. The magnetic flux lines form closed loops linking the circuit, and the lines of electric flux originate from one conductor and terminate on the other conductor.

Variation of the current in the conductors causes a change in the number of lines of magnetic flux linking the circuit and an induced voltage proportional to the rate of change of flux. Inductance is the property of the circuit that relates the voltage induced by changing flux to the rate of change of current.

On the other hand, the potential difference between the conductors of a transmission line causes the conductors to be charged in the same manner as the plates of a capacitor are charged when a potential difference is applied across the plates of the capacitor. Capacitance between parallel conductors is a constant depending on the size and spacing of the conductors and their height above the ground. For power lines less than 50 miles long, the effects of capacitance is slight and is usually neglected. For longer lines of higher voltage, capacitance becomes increasingly important.

This experiment is concerned with the calculation of inductance and capacitance of single phase transmission lines with stranded conductors.

Object: Calculation of inductance and capacitance of a single phase transmission line composed of stranded conductor:

The stranded conductors for overhead power transmission lines are composed of strands of wire with alternate layers spiraled in opposite

directions. Spiraling alternate layers in opposite directions prevents unwinding and provides flexibility with large cross-sectional area. A general formula for the total number of strands in the conductor is:

$$\text{Number of stands} = 3n^2 - 3n + 1 \qquad (1)$$

where: n is the number of layers including the single central strand

In order to calculate the the inductance of the single phase transmission line, one may use the following expression:

$$L = 2 * 10^{-7} \ell n \frac{D_m}{D_s} \quad \text{henrys/meter} \qquad (2)$$

where D_m is the geometrical mean distance between the two phase conductors, and D_s is the self geometrical mean distance or geometrical mean radius for each phase conductor (including the factor $e^{-1/4}$)

The capacitance of single phase transmission line with stranded conductors (neglecting the effect of ground) is expressed as follows:

$$C_n = \frac{2\pi\varepsilon_0}{\ell n \frac{D_m}{\overline{D}_s}} \quad \text{Farad/meter} \qquad (3)$$

where C_n is the capacitance of transmission line to neutral

$\overline{Ds}$ is the geometrical mean radius for each conductor (excluding the factor $e^{-1/4}$)

The capacitance of single phase transmission line with stranded conductors taking the effect of ground into account is expressed as follows:

$$C_n = \frac{2\pi\varepsilon_0}{\ell n \frac{\overline{D}_m H}{\overline{D}_s F}} \quad \text{Farad/meter} \qquad (4)$$

where H is the vertical distance between the conductor and its image.

F is the distance between the conductor and the image of the opposite conductor.

As a check, the calculated capacitance C and inductance L should satisfy the expression:

$$\frac{1}{\sqrt{LC}} = 3 * 10^8 \text{ m/sec} = \text{light velocity} \qquad (5)$$

Procedure:

Prepare an algorithm to calculate the inductance L and capacitance C of a single phase transmission line with stranded conductors. Use the algorithm to build up a Fortran program to calculate L and C. The following steps outlined in the flow chart shown in Fig. 1 may help in preparing the computer program.

1. Find the GMD of each conductor.
2. Determine the GMR of each conductor
3. Determine the capacitance and inductance of the transmission line using equations (2) & (3) or (4)
4. Use eq. (5) to check the accuracy of calculation
5. Compare with the values reported in the tables given in Ref. [1] for stranded conductors with 7 and 37 strands.

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[1] w. Stevenson – **Power System Analysis.**

Prerequisite:

For any number of strand layers, determine the number of strands and thei coordinates for both conductors of the single phase transmission line.

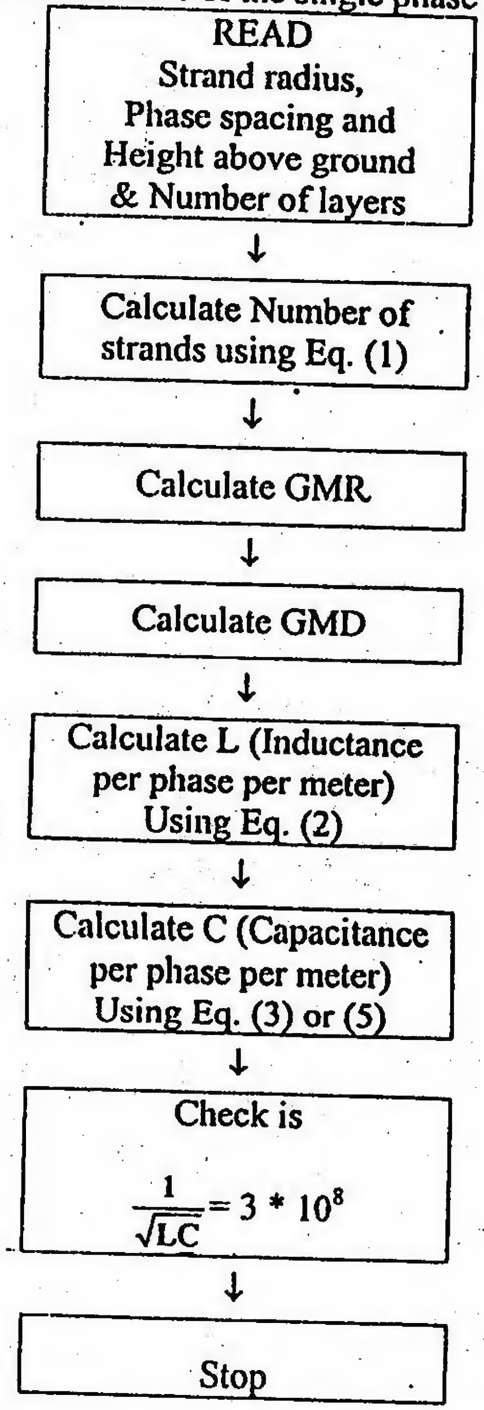


Fig. 1 Flow chart to calculate the inductance and capacitance of transmission line per phase per meter.

(III)

Power Electronics Experiments

(1)

Simple Rectifiers

Objective

Observation

The performance of half-wave and full-wave rectifiers, the effect on their performance of loads comprising resistance alone, with capacitance or with inductance, and the distinction between average (or mean) and rms values of voltage and current.

Apparatus required

PE481 Control Unit

PE481A Single Thyristor Circuits

PE481 Load Unit

Connecting leads

Two-channel oscilloscope

Prerequisites

The student should read the operating notes on the preceding pages, to familiarize himself with the equipment, and its supplies, controls, and indicators.

I- Experiment 1.1 – Performance of a Half-Wave Rectifier

(a) With Resistive Load

(i) Plug the PE481A module into the socket of the 'power module' position on the right side of the control unit. Connect the apparatus as shown in fig 1.1. This forms the circuit shown in fig 1.2, in which the 'flywheel' diode is used as the rectifying element. (The word 'flywheel' is not relevant here, but relates to its use in later experiments).

Before switching on, check your connections and set up the controls as follows.

(ii) The flywheel diode switch should be switched 'in'.

(iii) The load resistor should be set to 50% on its scale. Since the whole resistance is 50 ohms, this sets a resistance value of 25 ohms.

The oscilloscope should have both Y channels set to a sensitivity of 20V/cm. The time base should be set to 5ms/cm and synchronized to the power line (if the oscilloscope has this facility, otherwise the Y2 channel should be selected for synchronizing).

(iv) Switch on the supply. Sketch the waveforms of load voltage (Y1) and the supply voltage (Y2).

(v) Establish a table of results in the form of fig 1.3, for the results of this experiment (half wave) and the next (full wave).

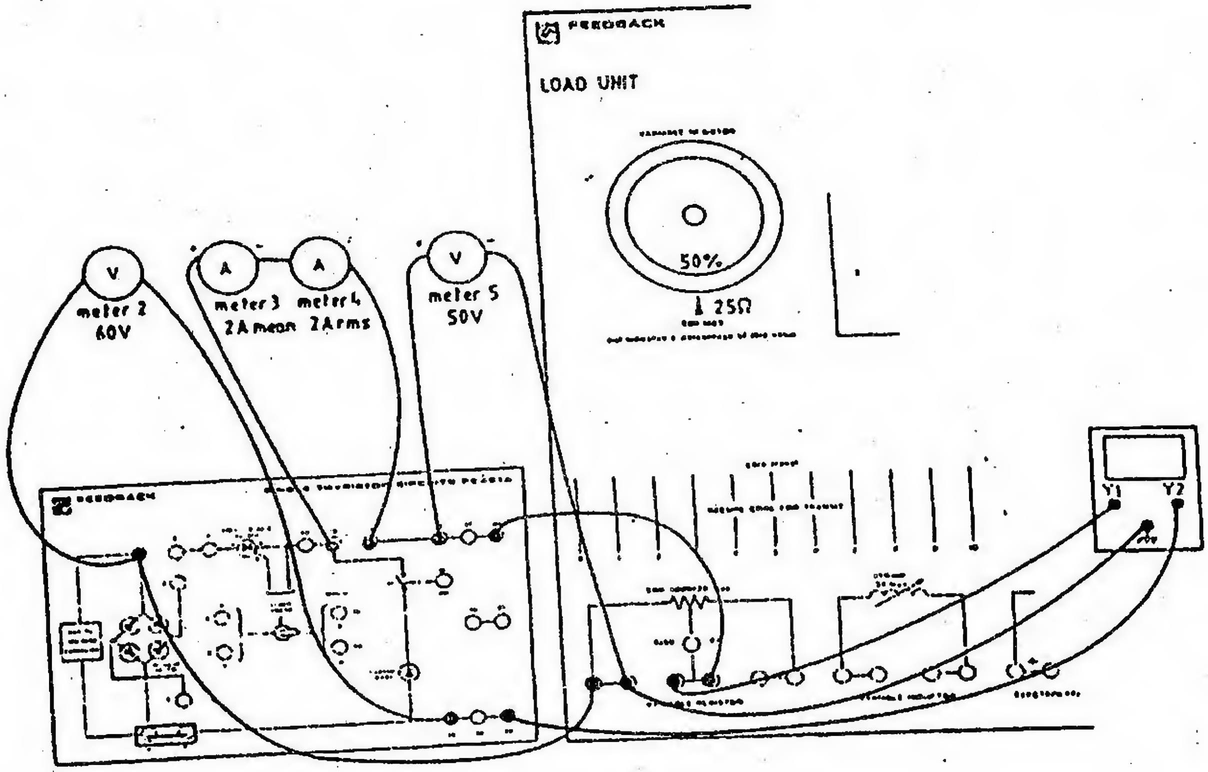


Figure (1-1)

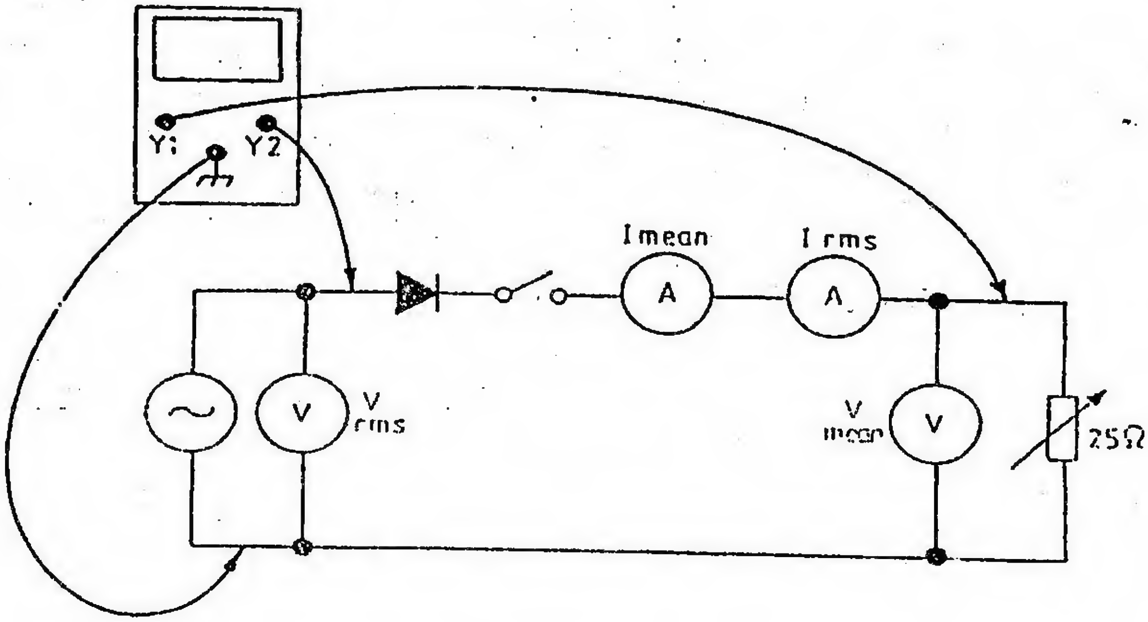


Figure (1-2)

(vi) Take readings of meters 2, 5, 4 and 3 to complete the first column of the table (half wave, resistive load) and note the load resistance.
Note the considerable difference between the average and rms values of the current (which is the same in each ammeter). This is typical of when the current waveform is 'peaky', i.e has periods of large current separated by periods of little or (as here) no current.

(b) With Resistive-Inductive Load

(i) Alter the load connections as shown in fig 1.4, to make the circuit of fig 1.5. (it is good practice, although not absolutely necessary, to switch off the equipment temporarily by the pushbutton switch when making circuit alterations).

(ii) Temporarily move the Y2 lead of the oscilloscope to the same point as Y1 and adjust the gain and shift controls of the oscilloscope so that the waveforms coincide on the screen. Then connect Y2 as in fig 1.4. Trace Y1 will display the load current waveform, since this is of the same form as the volt-drop across the resistance.
The inductor has a resistance of about 2-5 ohms, so reduce the variable resistance by this amount to restore the total resistance to 25 ohms.

(iii) Fill in the following table.

	Half wave			Full wave		
Load	R	R-L	R-C	R	R-L	R-C
Supply V rms Load V mean Supply I rms Load I mean Load resistance						

Figure (1-3)

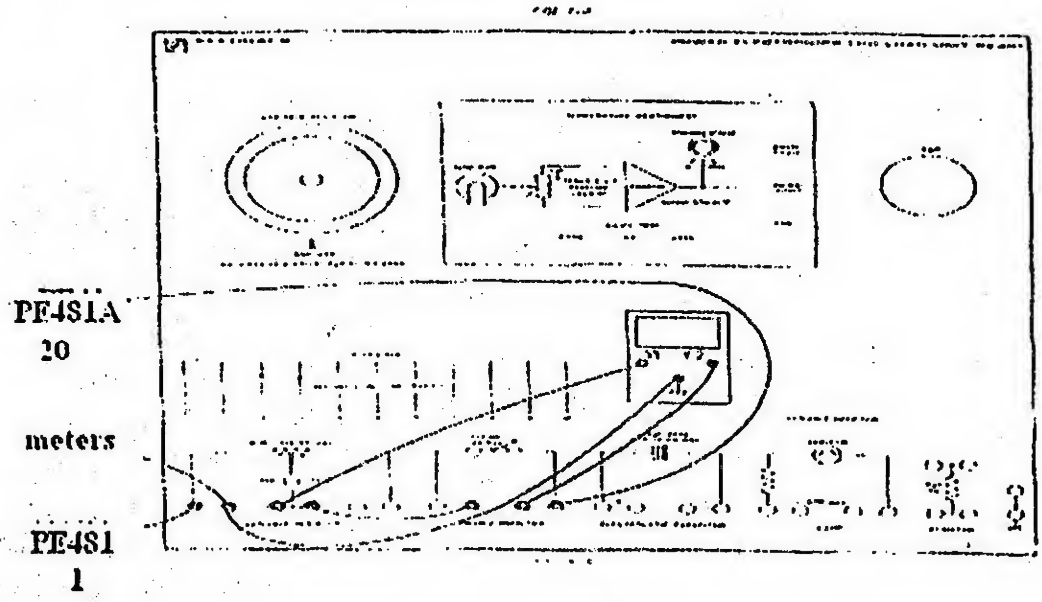


Figure (1-4)

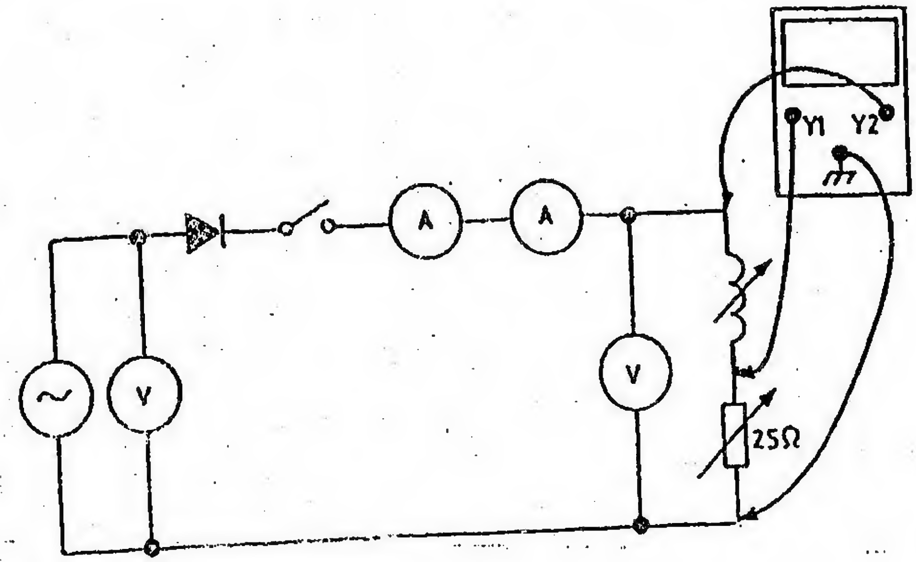


Figure (1-5)

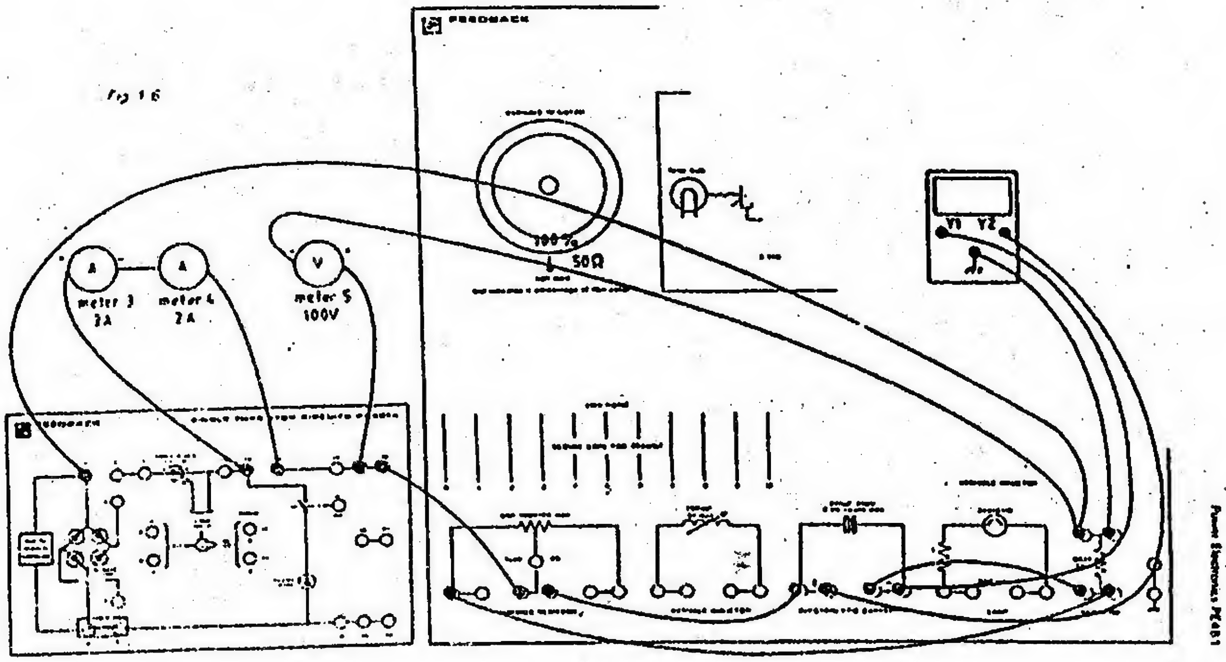


Figure (1-6)

(iv) Remove the core of the inductor.
(v) Switch on and observe the waveforms of load voltage (Y2) and current (Y1). Continue to observe as the inductance is slowly increased by re-inserting the core.
(iv) Answer the following questions?
Q1.1 Why does the instantaneous load voltage no longer become zero from the time when the supply voltage passes through zero?
Q1.2 Why does current continue to flow after the supply voltage has reversed?
(v) With the inductance set at maximum (carefully inserted), take a further set of readings and complete the second column of the table.
The average voltage is the total 'volt-second area' per cycle, and the 'area' appearing after the supply has reversed, is negative.
Notice that the inductance reduces the load voltage, because with the inductance circuit there is a negative 'area' but with no inductance there is no negative area, while the inductance leaves the positive 'area' unchanged.

(c) With Resistive-Inductive Load

(i) Connect the apparatus as shown in fig 1.6. This forms the circuit shown in fig 1.7. Note the change of range of meter 5, and be particularly careful to ensure that the electrolytic capacitor is connected with the correct polarity.

(ii) The load resistor should be set to 100% on its scale, 50 ohms.

(iii) The oscilloscope should have Y2 channel left at a sensitivity of 20V/cm; Y1 should be set to 2V/cm.

(iv) Sketch the waveforms of supply current (Y1) and load voltage (Y2).

(v) Take a further set of meter reading and complete the third column of the table.

Notice the even greater difference between the average and rms values of the current (which is the same in each ammeter) than with purely resistive load, because the current pulses are shorter.

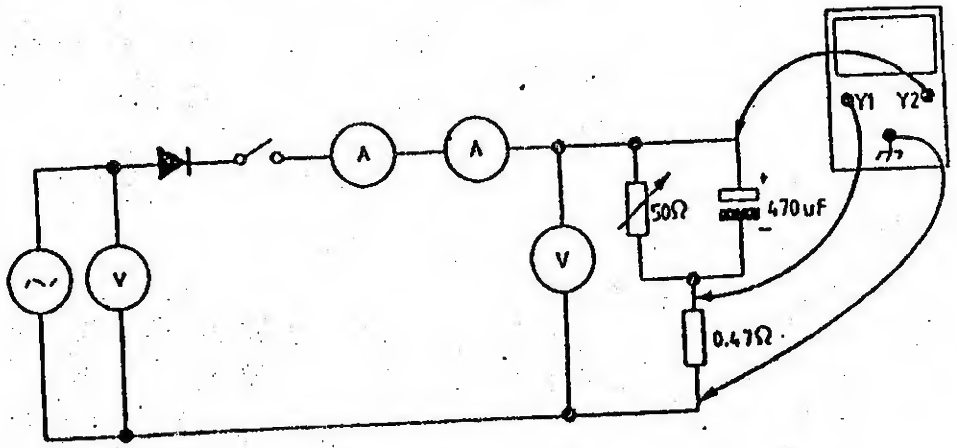


Figure (1-7)

(vi) Answer the following questions?

Q1.3 Why is the average load voltage shown on meter 5 so much greater than in the previous cases?

Use the oscilloscope (Y1) and 0.47-ohm resistor to determine the peak current.

Q1.4 What is the peak current and what is the ratio of peak to mean current?

(II) Experiment 1.2 – Performance of a Full-Wave Rectifier

(a) With resistive load:

(i) Connect the apparatus as shown in fig 1.8, connect link 1 but not link 2. This circuit does not use the flywheel diode; this time the rectifier is the full-wave bridge rectifier at the left of the module.

The oscilloscope should have Y1 channel set to 20V/cm and Y2 to 0.5V/cm.
(ii) Switch on the supply. Sketch the waveforms of load current (Y2) and the rectified supply voltage (Y1).
(iii) Take a set of meter readings as before and complete column 4 of the table (fig 3).

(b) With inductive load:
(i) Remove link 1 and take a further set of readings.
(ii) Observe the effect on the waveforms of varying the inductance. Sketch the waveforms of load current and voltage now obtained with maximum inductance.
(iii) Notice that the instantaneous load current no longer falls to zero as it did in the half-wave circuit, because the inductance generates an emf which maintains the load current, even at the moment of zero voltage and current in the supply. This current always flows through the rectifier along a path such that the supply voltage aids the maintenance of current; there is no negative 'volt-second area' from the supply.

(d) Answer the following questions?
Q1.5 Why does varying the inductance now make no difference to the average load voltage?
(iv) Replace link 1 and add link 2 in the position indicated in fig 1.8, forming a parallel resistance-capacitance load.
The oscilloscope should have Y1 channel left at a sensitivity of 20V/cm; Y2 should be set to 1V/cm.
(v) Sketch the waveforms of supply current (Y2) and load voltage (Y1).
Take a further set of readings and enter them in the table, including a reading of the peak current.
(III) Summary of the Results
Your results should be consistent with the following table, which lists ratios of quantities which are practically useful measures of performance.
The ratios have been chosen so that large values of each are desirable.
It can be seen that the half-wave rectifier has poor performance in at least one respect, whichever type of load is in use.
The other significant point to notice is that with a capacitor, even in the full-wave case, the peak current is about three times the mean current. At switch-on, since the capacitor is discharged, enormous currents can flow, and it takes only quite a short pulse of current to destroy a semiconductor device. Therefore in high-power applications, circuits are avoided in which a

semiconductor rectifier is directly connected to a load including parallel capacitance.

	Half wave			Full wave		
Load	R	R-L	R-C	R	R-L	R-C
Load V mean / Supply V rms	0.45	0.38	1.04	0.9	0.9	1.2
Load I mean / Supply I rms	0.64	0.67	0.55	0.9	0.93	0.63
Load I mean / Supply I peak	0.45		0.16	0.9		0.41

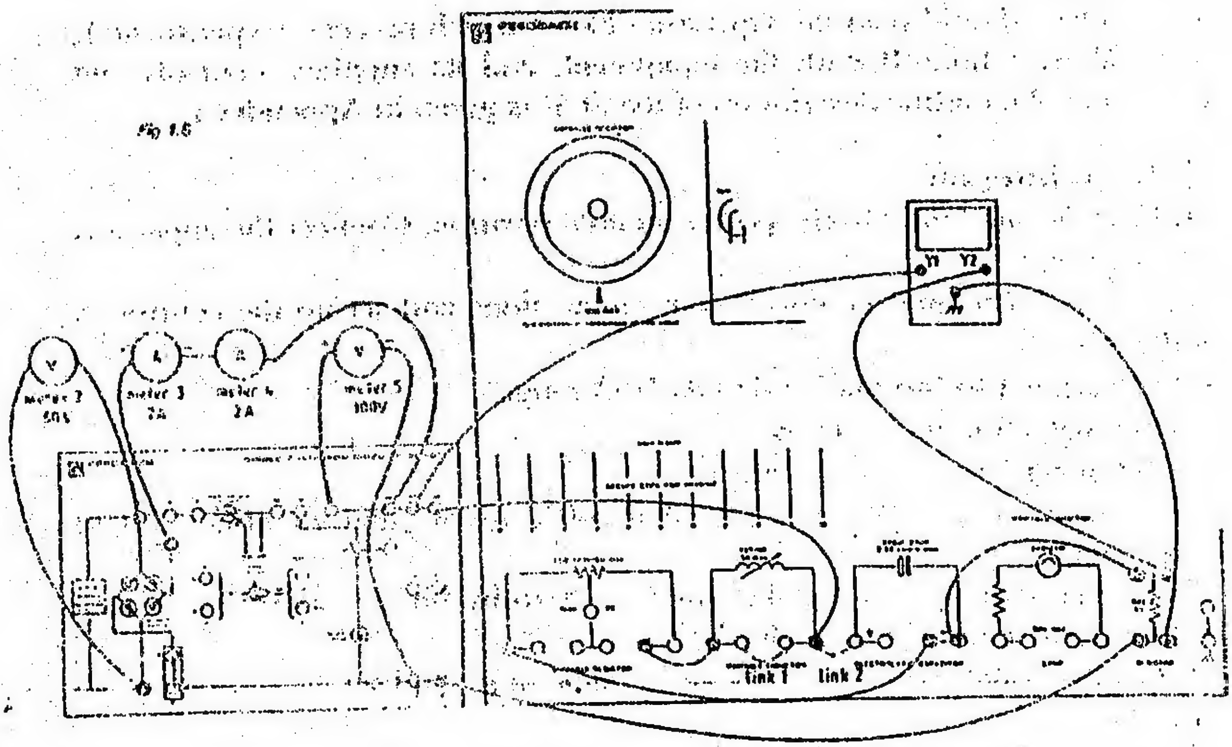


Figure (1-8)

(2)

Silicon Controlled Rectifier (SCR) – D.C Tests

Objective

2.1 Switching on – to demonstrate that a SCR in response to a low-power signal will switch on a signal of much greater power.

2.2 Switching off – to discover conditions needed to turn off the SCR 'switch'

2.3 Behaviour with anode negative – to demonstrate that a SCR is (as the name implies) a rectifier, i.e conducts in one direction only.

Apparatus required

	PE481	Control Unit
PE481A	Single Thyristor Circuits	
PE481	Load Unit	
Connecting leads		

Prerequisites

The student should read the Operating Notes which precede Experiment 1, to familiarize himself with the equipment, and its supplies, controls and indicators. An outline description of the SCR is given in Appendix 1.

(I) Switching on

(a) Plug the module into the power module position. Connect the apparatus as shown in fig 2.1.

(b) Before switching on, check your connections and set up the control as follows.

(c) Set meter 1 to 'normal' and to its 1mA range.

(d) Set meter 3 to its 2A range.

(e) Set meter 5 to its 50V range.

(f) Set the variable-resistance load to 60% on its dial to obtain 30 Ω resistance.

(g) Set the variable-voltage d.c supply to zero by turning its rotary control fully anticlockwise; set it to the 5V range.

(f) On the module, switch the flywheel diode 'out', and set the trigger switch to 'ext'.

(j) Then switch on the main supply. Initially there should be no response from the meters. Note that no anode current (meter 3) flows in the absence of any gate current (meter 1).

(i) Raise the voltage of the variable-voltage d.c supply slowly, watching the anode current meter (meter 3).

(c) Answer the following questions?

Q2.1 What happens in the anode circuit as the variable voltage of the d.c supply rises?

Turn the control of the variable-voltage d.c supply fully anticlockwise again. Try momentarily disconnecting the trigger signal from the trigger switch on the module.

Q2.2 What happens in the anode circuit when the gate current is removed?

(m) Momentarily break the anode circuit by disconnecting the +15V lead from the anode (A) terminal of the SCR, and then reconnecting it. You should find that the anode current remains at zero after this.

(n) Repeat the experiment, this time looking the gate current shown on meter 1. Find the approximate value of the gate current (meter 1) just before the DCR starts to conduct anode current (meter 3). It may be necessary to repeat several times the cycle of breaking the anode circuit to stop the anode current, reducing the gate current, reconnecting the anode circuit and carefully raising the gate current, before you see clearly what is happening; however a value of gate current within 10% of the true value is quite good enough.

(e) Answer the following questions?

Q2.3 How much gate current was required to switch on the SCR?

Q2.4 What was the approximate ratio of the anode current change at switch-on to the gate current which caused it?

Without disturbing the setting of the variable supply, switch meter 1 to measure its voltage, i.e the gate circuit voltage just before anode current started to flow.

Q2.5 What gate circuit voltage was required?

Q2.6 What was the approximate ratio of voltage controlled in the anode circuit to the gate voltage?

(g) You should have found that:

Application of a small voltage and a small current to the gate of the SCR switches on a much larger current and voltage in the anode circuit.

Removal of the gate signal alone does not switch the anode current off.

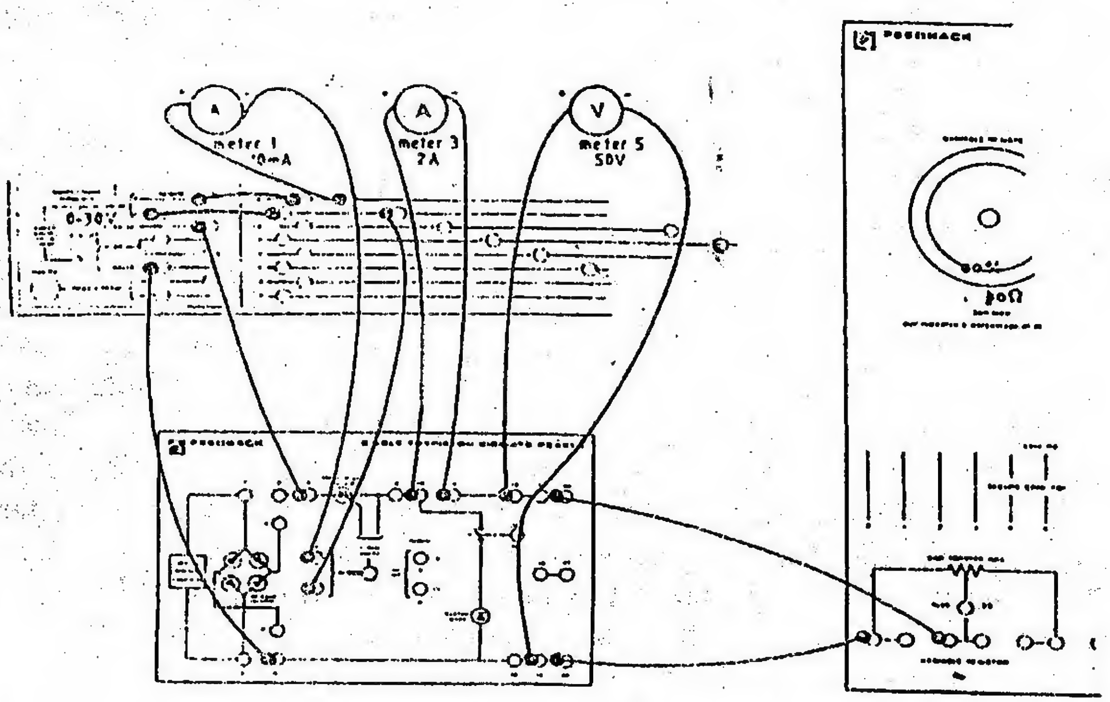


Fig 2.1

Figure (2-1)

(II) Switching Off

(a) Disconnecting the anode circuit to switch off the SCR is not usually practicable, so that we need to know more precisely what happens.

(b) Reconnect the apparatus as shown in fig 2.2 leaving all other connections unchanged. Before switching on, check your connections and set up the controls as follows.

(c) Set meter 1 to its 10mA range.

(d) Set the variable-resistance load to 100% on its dial to obtain the maximum resistance.

(e) Set the variable-voltage d.c supply to zero by turning its rotary control fully anticlockwise, and make sure that its switch is set to the 5V range. Then switch on the main supply and set to the 5V range.

Then switch on the main supply and set the 'trigger' switch on the module to 'ext' thus applying a large d.c trigger signal to the SCR gate.
As the voltage of the variable-voltage d.c supply raised, anode current (meter 1) starts to flow. It will continue after the gate current is removed. (This is most easily done by switching the 'trigger' switch to 'int' since no internal trigger source is present).
(f) Reduce the setting of the variable-voltage d.c supply until the current shown on meter 1 is about one-tenth full scale. If you succeed, follow the instructions in paragraph II (B).
(II-A) If the current ceases before you get to one-tenth full scale, repeat the process, by raising the variable-voltage d.c supply setting slightly, switching 'trigger' momentarily to 'ext' and then back, and then again reducing the setting carefully to establish what is the value of the current just before it ceases.
(II-B) If (and only if) you got down to one-tenth full scale (i.e 1mA), then switch the range of meter 1 to 1mA. If there is still a current flowing, reduce the variable-voltage d.c supply setting carefully to find out how low a current can be maintained. The current may cease when you change the meter range. If so, switch the trigger' switch to 'ext', which should restore some current; adjust the variable-voltage d.c supply carefully to give 1mA. Then switch back to 'int' and try reducing the variable-voltage d.c supply setting carefully to find out how low a current can be maintained.
(II-C) Answer the following questions?
Q2.7 What was the lowest anode current which could be maintained?
With the equipment set so that the minimum possible anode current is passing (and no gate current), disconnect the anode lead momentarily, then reconnect it. Then switch 'trigger' momentarily to 'ext' and then back.
Q2.8 Was current re-established at the minimum level, or did the setting of the variable-voltage d.c supply have to be raised slightly to regain conduction?
You should have found that in order to stop the anode current it was necessary to reduce the current, by means external to the SCR, below a critical value which is called the 'holding current'. With some (but not all) SCR's it is found that while injecting a gate current will reestablish anode conduction, it will not continue when gate current ceases, unless the anode current is raised to a higher value than the holding current. This higher value is called the 'latching current'.

(III) Behaviour With Anode Negative

(a) Leaving the same connections, switch meter I to the 100mA range, switch 'trigger' to 'ext' and adjust the variable-voltage d.c supply to give 100 mA of anode current. Then disconnect the leads from the variable-voltage d.c supply output sockets (at the left-hand end of the control unit), and reconnect them with reversed polarity. Correct the polarity of the meter by turning the 'forward/reverse' switch t 'reverse'.
(b) Q2.9 What is the anode current now?
You should have found that when the anode was negative with respect to the cathode the current flowing in it was small, in keeping with the 'rectifier' description of the SCR. However keeping the gate positive with respect to cathode does increase the anode's leakage current.

(IV)Summary

In this experiment it was found that in an SCR:
Forward conduction does not occur until a positive signal is applied to the gate. The required gate signal is small compared with the voltage and current in the anode-cathode circuit.
Once established, forward current persists independent of the gate, until reduced below the holding current by external means in the anode circuit.
Reverse conduction does not occur, apart from some leakage if a positive gate signal is applied.

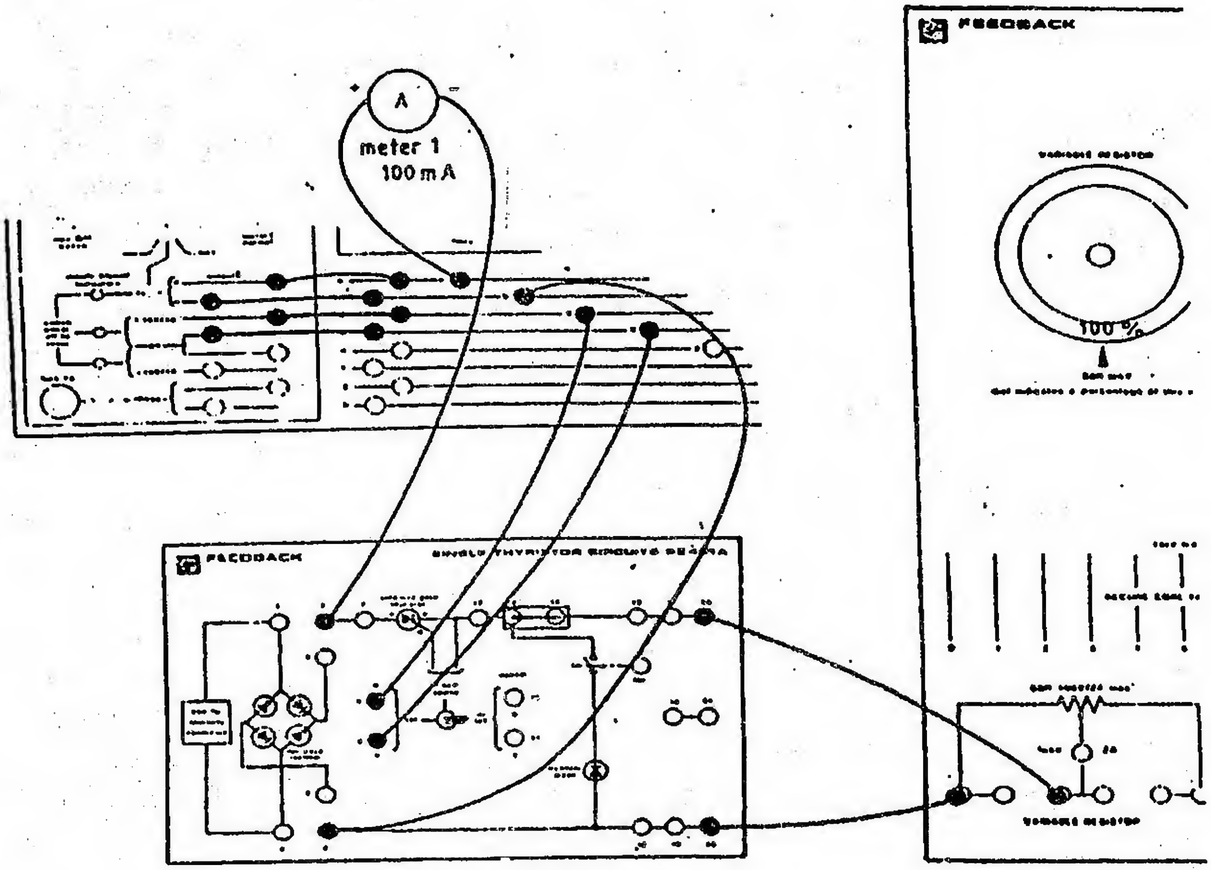


Fig 2.2

Figure (2-2)

(3)
Rectification Using the SCR

Objective
Experiment 3.1 - Dynamic characteristics of the SCR – oscilloscope display
Experiment 3.2 – Half-wave rectification with control of load voltage by a signal to the gate unsatisfactory nature of control by a d.c gate signal.

Apparatus required

PE481 **Control Unit**
PE481A **Single Thyristor Circuits**
PE481 **Load Unit**
Oscilloscope, two-channel, with X-Y facility Connecting leads

Prerequisites
If required, an outline description of the SCR may be found in appendix 1.

(I) Experiment 3.1 - Dynamic Characteristics of The SCR
The X-Y oscilloscope will be used to demonstrate the SCR's characteristic dynamically.

(a) Plug the PE481A module into the power module position.

(b) Connect the equipment as shown in fig 3.1. The reason for the load resistor being connected as shown is that many general-purpose oscilloscopes, when operated in X-Y mode, have only very limited control over the X channel sensitivity; the connection shown uses the load resistor also as a gain control potentiometer for the X channel.
The Y channel sensitivity setting should be 20V/cm.

(c) Set meter 3 to its 2A range.

(d) Switch on the equipment and raise the output of the variable-voltage d.c supply (which supplies a d.c gate signal) until maximum load current flows (about 0.45A mean). Adjust the X channel and the load potentiometer to give a satisfactory display. This should be an L-shaped display like fig 3.2a, since the SCR should ideally conduct current I_f perfectly in the 'forward' direction, and pass no reverse current for any value V_r of reverse voltage. Note that the displayed graph would on paper normally be shown turned through 90 degrees, fig 3.2b. Disconnect the gate signal by switching the 'trigger' switch to 'int'. (Three is no internal trigger signal present).

(e) Sketch the characteristic displayed on the oscilloscope when gate current is removed.

Switch the 'trigger' switch back to 'ext', and adjust the output of the variable-voltage d.c supply carefully until the load current takes a lesser value. (It may be difficult to get a steady value, but this does not matter). Observe carefully the way that the display alters, including any variation in trace brightness which may suggest where something sudden happens.

(f) Sketch the display in this condition. Label the axes of the displayed graph indicating 'forward' and 'reverse' directions of both current and voltage. If you need help, take a look at fig A1.5 in Appendix 1, bearing in mind that the display on the oscilloscope is not the same way up.

You should have found that altering the gate signal over quite a small range alters the 'break-over voltage' (see Appendix 1) over a large range.

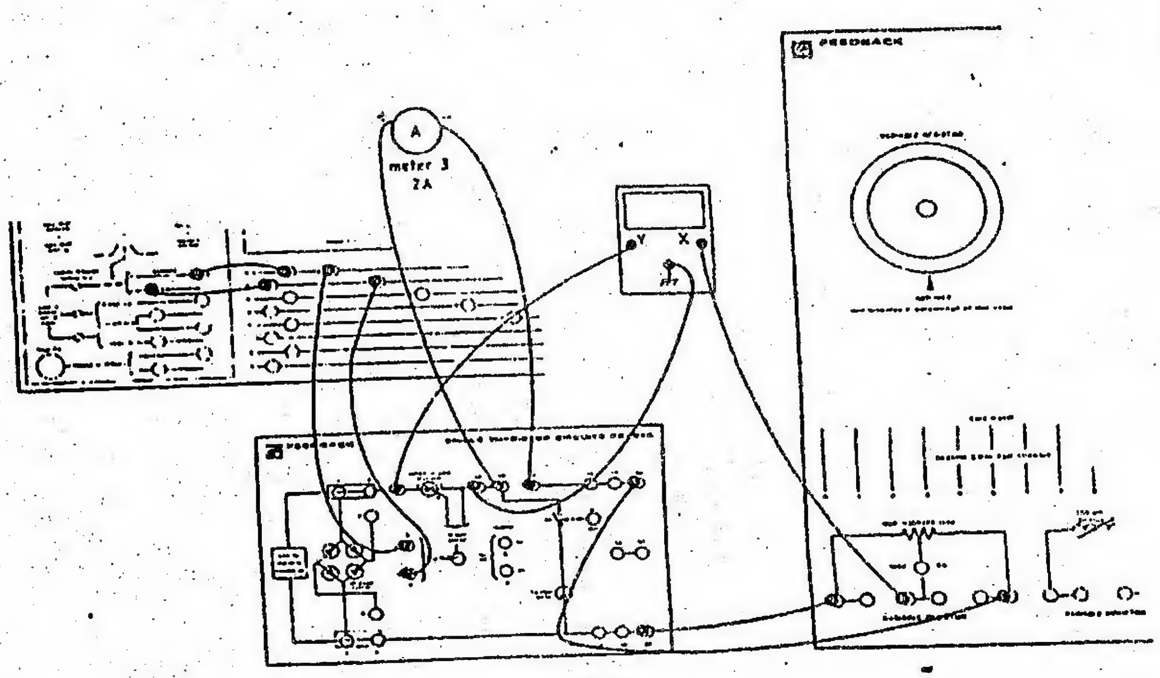


Fig 3.1

Figure (3-1)

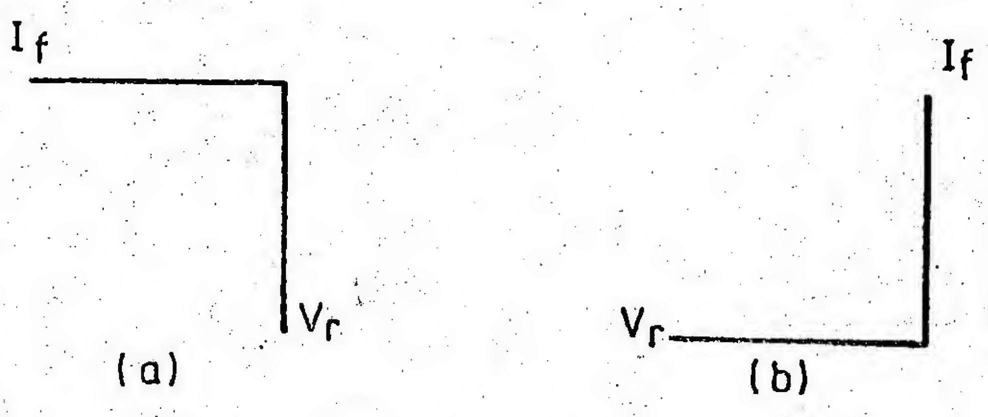


Figure (3-2)

(II) Experiment 3.2 – Half-Wave Rectifier, DC Gate Control

(a) Connect the equipment as shown in fig 3.3. Set the switch of the variable-voltage d.c supply to the 5V position and turn the variable control fully anticlockwise. Set the meters as indicated. The load resistor should be set for 40% resistance, i.e 20 ohms.
(b) Set the oscilloscope controls as follows:
Y sensitivity 20V/cm (both channels) Time base 5ms/cm, synchronized to Y1 or to the power line.
(c) Adjust the oscilloscope Y1 channel to give a steady display of the module's supply, which is nominally 50V rms. Set the Y2 trace near the bottom of the screen. (At this stage it will just be a straight line)
(d) Adjust the oscilloscope Y1 channel to give a steady display of the module's supply, which is nominally 50V rms. Set the Y2 trace near the bottom of the screen. (At this stage it will just be a straight line).

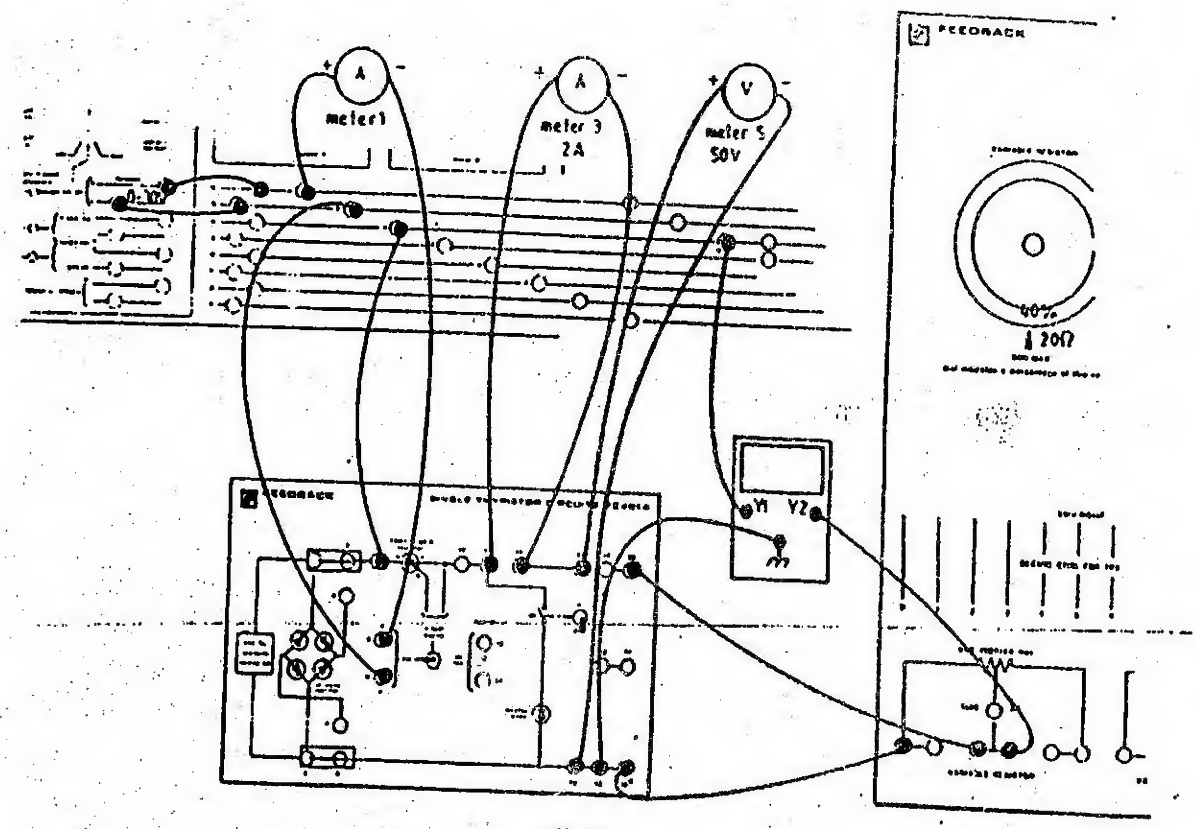


Fig 3.3

Figure (3-3)

(e) Now raise the voltage of the variable-voltage d.c supply. When it is raised far enough you should find that meter 3 shows a reading of about 1A, and the waveform of the voltage across the load resistor (which is also that of the current in it) is shown on the Y2 trace of the oscilloscope.

(f) Sketch the supply and load waveforms, marking in each case where the OV level lies on the waveforms.

Note that with the gate signal applied, the SCR behaves very similarly to a simple diode rectifier.

Now reduce the output of the variable-voltage d.c supply to zero. The output current ceases.

(g) In Experiment 2.1 is was found in a similar circuit having a d.c supply, the load current did not cease when the gate current was removed. Why is this case different?

(h) By varying the output of the variable voltage d.c supply, try to establish some value of load current less than maximum (1A) which you had before. It will be necessary to make very fine adjustments to achieve this, and the

output current may not be very steady. The reason may become apparent from fig A1.5 in Appendix 1.

(i) Answer the following questions:

- Sketch the load waveform at an intermediate current.

- Experiment 3.1 showed that varying the d.c signal to the gate altered the break over voltage. Can you suggest why it is impossible to reduce the current to a value below half the maximum using this form of control?

(III) Summary

You should have found that:
The SCR behaves very much like a diode rectifier, when gate current is supplied. The gate signal is able in effect to control the switching off, as well as the switching on, of load current, when the anode current is forced to zero by a means external to the SCR (i.e by the alternating supply in this case).
Control to achieve low output currents is possible, but only within limits, and even then it is not satisfactory.

(4)
Characteristics of The Triac

Objectives
4.1 – Response of the triac to positive and negative d.c gate signals.
4.2 – Dynamic characteristic of triac – oscilloscope display.

Apparatus Required
PE481 Control Unit
PE481C AC Thyristor Circuits
PE481 Load Unit
Oscilloscope, two-channel, with X-Y facility Connecting leads

(I) Experiment 4.1 - Response of The Triac to Positive and Negative d.c Gate Signals.

Notice that on the module the triac's load-circuit terminals are marked T1 and T2, not A and K as for the SCR. This is because, as we shall see, the triac permits load current to flow in either direction. It is not therefore a rectifier, although it can be controlled in much the same way as the SCR can be. Notice also that the gate signal is applied between the gate and T1 terminals.

(a) Plug the PE481C module into the power module position. Connect the equipment as shown in fig 4.1. Set the meters as indicated. Set the switch of the variable-voltage d.c supply to the 30V position and turn the variable control fully anticlockwise. The load resistor should be set for 50% resistance i.e 25 ohms.

(b) Set the oscilloscope controls as follows:
Y sensitivity 50V/cm, both channels (for which on some oscilloscopes it will be necessary to use the variable gain control).
Time base 5ms/cm, synchronized to Y1 or to the power line.
Adjust the oscilloscope Y1 channel to give a steady display of the module's supply, which is nominally 50V rms. Set the Y2 trace near the bottom of the screen. (At this stage it will just be a straight line).
Now raise the voltage of the variable-voltage d.c supply, watching the Y2 trace of the oscilloscope carefully. As the variable voltage is raised you should see a waveform of load voltage appear, and at the same time a current will be indicated on meter 4, and a voltage on meter 5.
Q4.1 What is the least value of gate current which will produce the greatest deflection of meter 5?

(c) Tabulate your answer as indicated in fig 4.2. Record a positive value, since the gate is positive with respect to terminal T1. Complete the first row of the table, including a sketch of the load waveform. The load current should be recorded as positive if it flows during the time that T2 is positive with respect to T1, or negative otherwise.

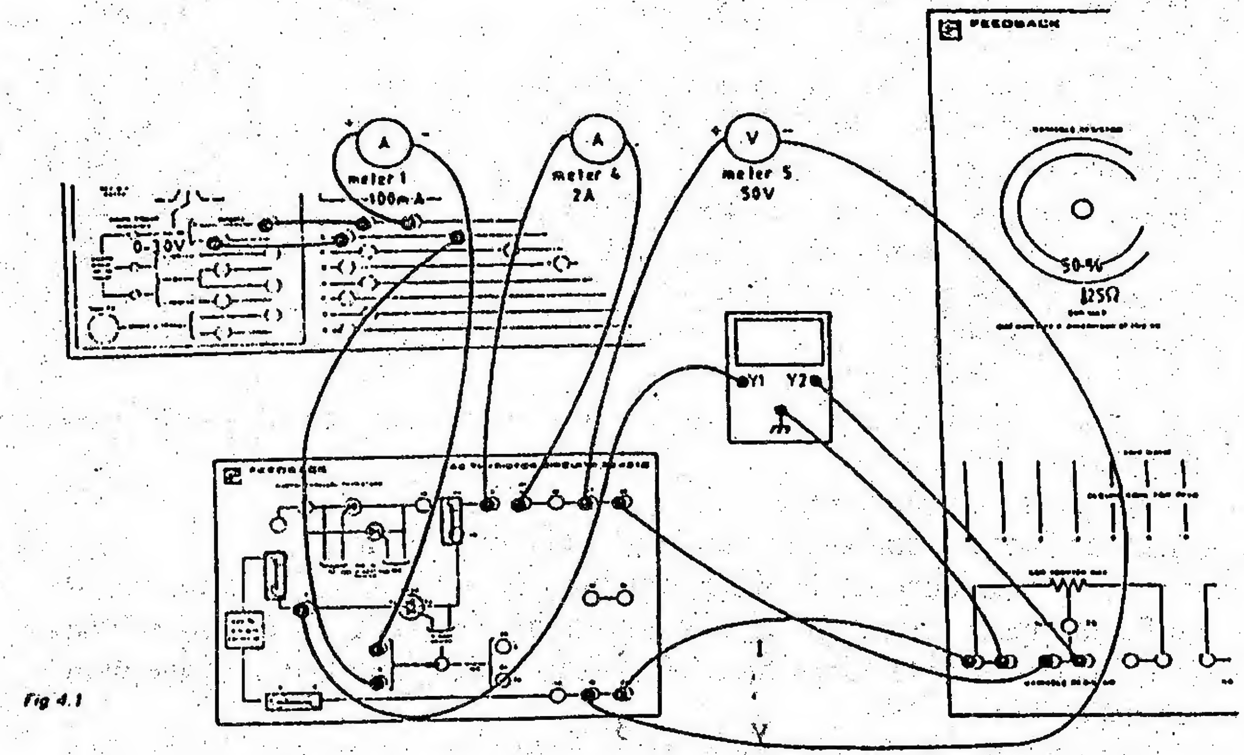


Figure (4-1)

Gate current (meter 1) mA d.c	Load current (meter 4) A rms	Load voltage (meter 5) V d.c	Waveform (sketch)

Figure (4-2)

(d) As the output of the variable-voltage d.c supply is raised further, the waveform of the load voltage may alter again. (This will usually happen, although in principle it may not, since a controlled characteristic for positive gate, negative T2 is not part of the device specification).

Q4.2 Did this happen in your case?

If so the d.c component of the load current and voltage will once again become small or zero

Q4.3 Why should the d.c load voltage reading decrease?

(e) If conduction occurred during both half cycles, enter a further line in your table to record the conditions.

(f) Now reverse the connections to the external trigger terminals, so that negative gate current will be supplied. Repeat Experiment 4.1 from the beginning, filling in two further rows of your table. Conduction should be possible on both half cycles this time. Do not forget that the gate current entries will be negative this time.

(g) Observe the indication on meter 5 and enter in your table the polarity of the output voltage.

You should have found that:

The triac does not conduct in the absence of any gate current.

The triac will conduct between terminals T1, T2 in either direction if sufficient gate current is supplied (with the possible exception of the combination of polarities where T2 is negative and the gate positive with respect to T1).

The amount of gate current required to establish conduction depends both on the polarity of conduction required, and on the polarity of the gate current.

(II) Experiment 4.2 – Dynamic Characteristic of Triac

The X-Y oscilloscope will be used to demonstrate the triac's characteristic dynamically.

(a) Connect the equipment as shown in fig 4.3. The reason for the load resistor being connected as shown is that many general-purpose oscilloscope, when operated in X-Y mode, have only very limited control over the X channel sensitivity; the connection shown uses the load resistor also as a gain control potentiometer for the X channel.

The Y channel sensitivity setting should be 20V/cm.

The meter setting are as before.

(b) Switch on the equipment with the variable-voltage d.c supply initially set to zero. The display should be a straight line along the voltage axis. Then raise the gate signal to give about 1A reading on meter 4 and adjust the X

channel gain and/or the load potentiometer to give a display which occupies most of the screen width. The display now stretches along the current axis in both directions.

(c) Starting again from zero gate signal, raise the output of the variable-voltage d.c supply progressively. It will be found that the display will develop segments in the direction of the current axis, showing conduction first in one direction, then in both.

(d) Sketch the display at various stages of its development from zero current to maximum. Label the axes on your sketches carefully.

(III) Summary

This experiment has shown in two different ways that a triac, like an SCR, conducts only when a gate signal is applied; but unlike an SCR the triac will conduct in either direction, in response to gate signals of either polarity.

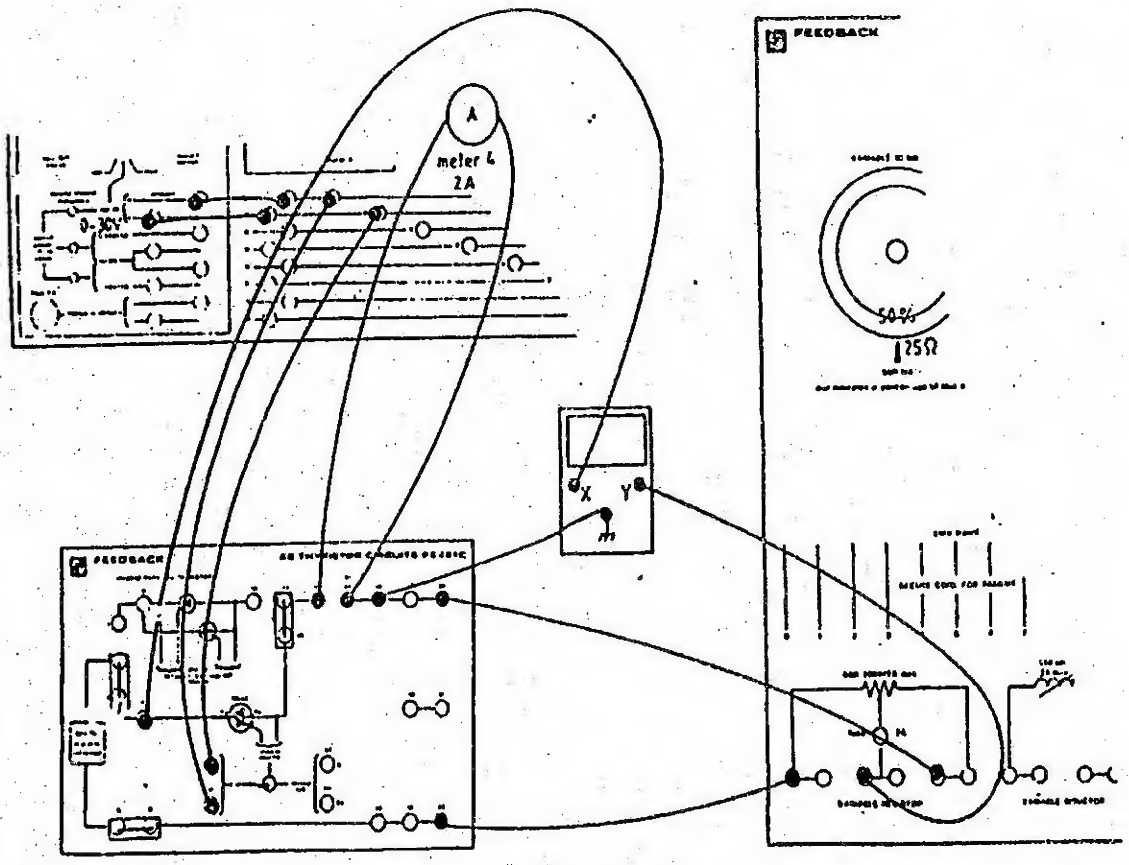


Fig 4.3

Figure (4-3)

(5)
Simple phase control Circuits

Objective

5.1 – Examination of three circuits – to observe arc of simple for effecting phase control of the gate signals to SCR's.
5.2 – Characteristic of the diac.

Apparatus Required

PE481 Control Unit
PE481A Simple Thyristor Circuits
PE481D Basic Trigger Circuits
PE481 Load Unit
Oscilloscope, two-channel, with X-Y facility Connecting leads

(I) Experiment 5.1 - Examination of Three Circuits

These circuits are based on the devices which are briefly described in Appendix 2.

(a) Phase Control

By timing the application of a positive signal to the gate of an SCR, it can be made to connect the supply to a load over part only of the supply cycle. The load voltage and current can thus be controlled.
To see this, plug the Basic Trigger Module PE481D into the left-hand ('control') socket of the Control Unit, and the Single Thyristor Module PE481A into the power module socket. (Plugging in the modules automatically connects the trigger circuit to anode and cathode respectively of the SCR).
(a) Connect the equipment as shown in fig 5.1.
Use the rotary switch on the Trigger Module to select circuit A.
(b) On the oscilloscope both Y channels should be set to 20V/cm sensitivity. Y1 shows the anode-cathode voltage; the Y2 channel shows the gate-cathode voltage.
(c) Vary the trigger control over its whole range. Observe that the load receives no voltage at the start of the positive half-cycle of the supply, but starts suddenly to have a voltage applied to it at a phase which is variable as the control is altered, and the current in the load is controlled accordingly.
(d) Sketch the load and supply waveforms for two different firing angles.

(e) Verify that much the same load waveform is obtained when the "circuit select" switch on the Basic Trigger Module PE481D is moved to the B position (ignoring the slight variation in position of the knob needed for a given output

The actions of the A and B circuits in the Basic Trigger Module PE481D are very different, as we shal now see.

(f) Disconnect the link which joins the SCR anode to the supply, and reconnect the oscilloscope as indicated in fig 5.2, first adjusting both traces to the center-line when no voltage is applied.

Select circuit A.

(g) Sketch the pair of waveforms, for each of two settings of the trigger control knob, taking particular care to mark where the OV level is on the Y2 waveform.

(h) Notice how this waveform descends with the negative-goihg supply because of conduction of D1 (marked on the module diagram). As the supply goes positive, the positive voltage is passed by D2 to the SCR, which then presents a low impedance, tending to clamp the waveform.

(i) Transfer the Y2 lead to socket 10 of the Single Thyristor Module, and adjust the sensitivity to 2V/cm. Add a sketch of this, the gate waveform, to the previous sketches.

(j) Select circuit B and reconnect the oscilloscope as in fig 5.2 again.

(k) Sketch the pair of waveforms, for each of two settings of the trigger control knob, marking where the OV level is on the Y2 waveform.

Note that the Y2 waveform is symmetrical about the zero line, so that there is no d.c component. Notice also the sawtooth sections of the waveform.

(l) Adjust the circuit and the oscilloscope (with time base say 1ms/cm) so that a few sawteeth are present, and well spread across the screen.

Now transfer the Y1 lead of the oscilloscope to terminal 1 of the single thyristor module. The Y1 trace should now show pulses at the same instant that each sawtooth step takes place. You may need to brighten the oscilloscope trace and look carefully to see them.

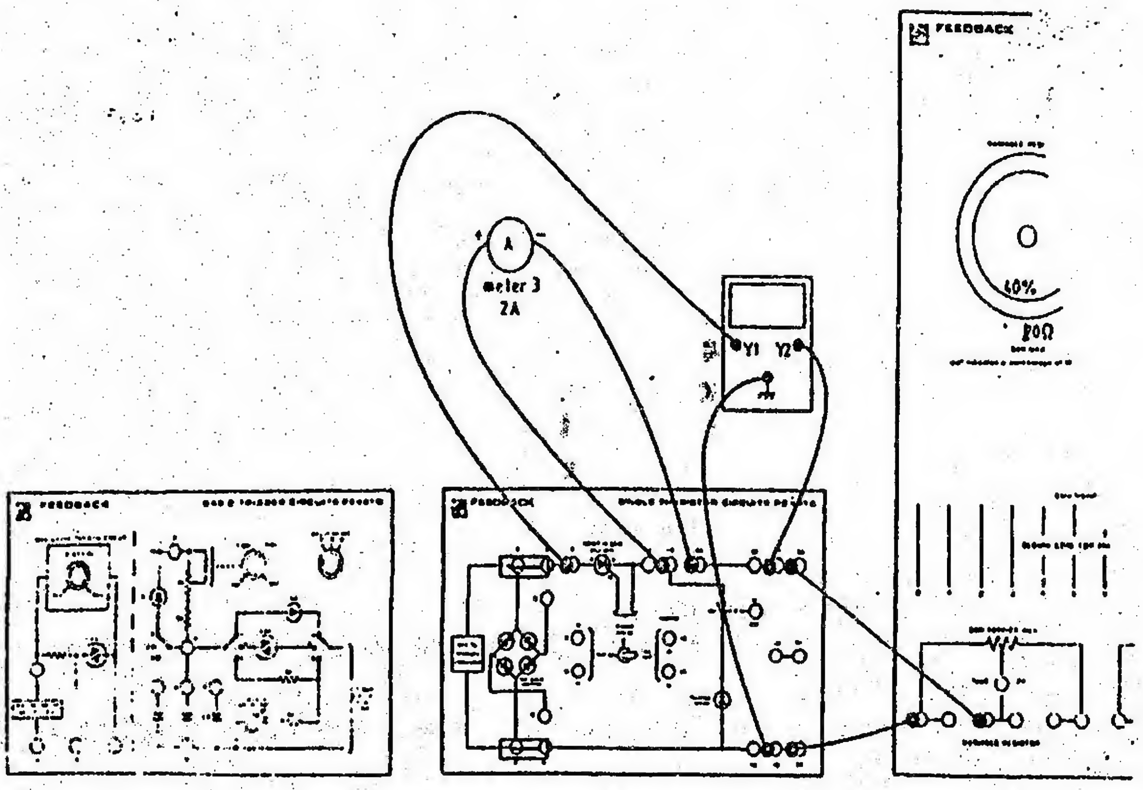


Figure (5-1)

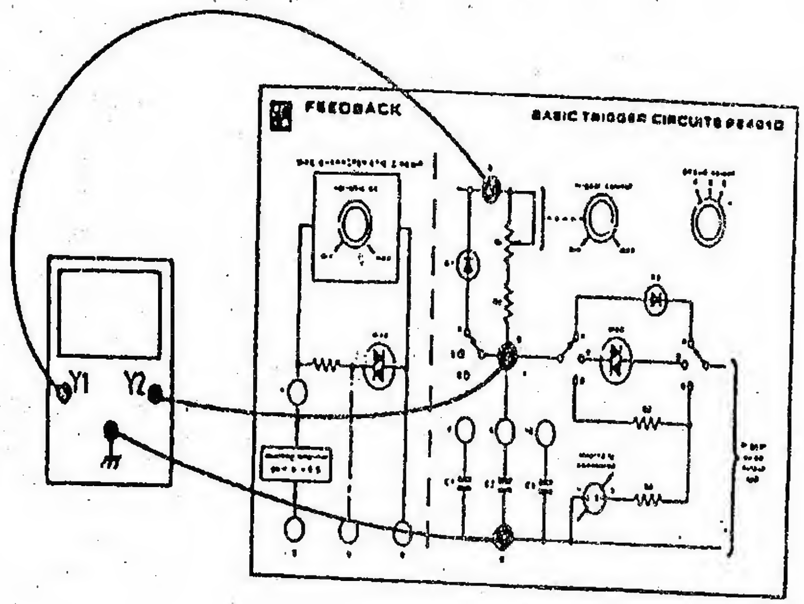


Fig 5.2

Figure (5-2)

(m) Answer the following questions?
Q5.4 What is the principal difference between this gate waveform and that seen with circuit A?
Connect the link on the single Thyristor Module between the a.c supply and the anode of the SCR.
Q5.5 What happens to the gate waveform when the anode is connected?

(n) The effect you observed is because the first of the pulses (usually) triggers the SCR into conduction, and when that happens the gate develops a low impedance and its potential is then largely determined by the conduction taking in Experiment 2 because of a resistor between the actual gate and the socket terminal).
(p) Circuit C is even simple. To use it, link capacitor C1 in parallel with capacitor C2 on the Trigger Module and switch to circuit C. You will see in a moment that this will introduce nearly 90 degrees phase shift into the RC network.

Increase the Y2 sensitivity of the oscilloscope to 0.5V/cm. Reset the time base to 5ms/cm. Transfer the Y1 lead to the a.c supply once more. Set the

variable d.c supply switch to the 5V range and the variable control to minimum.

(q) Best results will be obtained with the 'trigger' control set to 'min'. Raise and lower the output of the variable-voltage d.c supply, which is added via R4 to the output waveform of the module. The oscilloscope will show the 90-degree lagging waveform shifting in d.c level, with distortion introduced by the conduction of the SCR gate. Because the waveform increases steadily during the half-cycle of interest, the more positive the d.c level, the quicker the waveform reaches a positive value sufficient to fire the SCR.

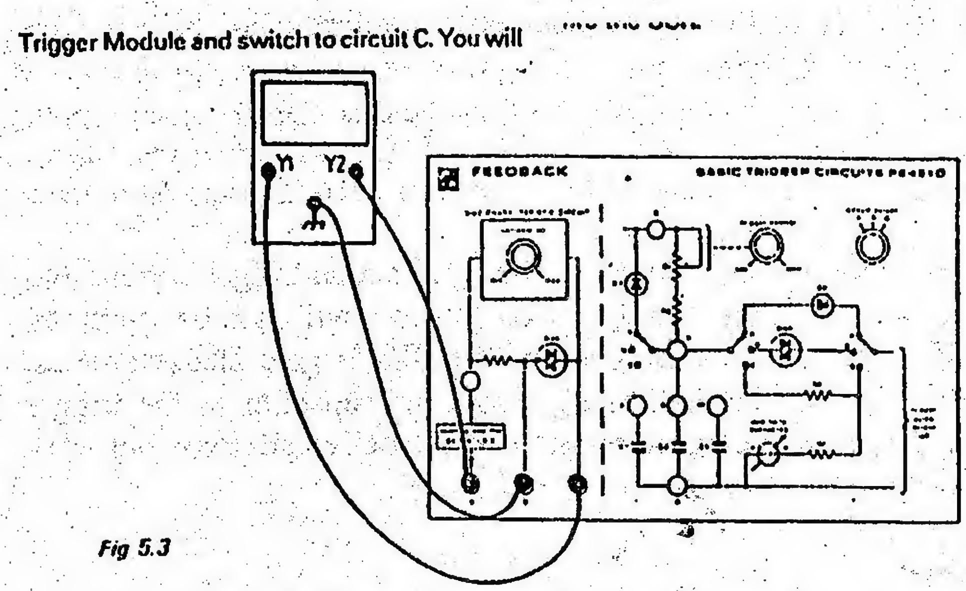


Fig 5.3

Figure (5-3)

(II) Experiment 5.2 – Diac Characteristics

(a) With The Basic Trigger Module PE481D plugged in-no wiring is needed, except to connect the oscilloscope to the 'Diac characteristic circuit' of the Basic Trigger Module PE481D, as indicated in fig 5.3. These connections place the Y1 channel across the diac itself. The Y2 channel sees an inverted version(also reduced in magnitude for technical reasons) of the voltage across the series resistor; it therefore displays the current in the diac.

(b) If the time base is left as before, the two waveforms wiii be seen as the 'variable a.c' knob is varied.

(c) Sketch the two waveforms

The start of the current pulse is clearly very sudden. A look at the characteristics of the diac should indicate why.

(III) Dynamic characteristic of diac

(a) Rearrange the oscilloscope so that it operates in X-Y mode.
As the 'variable a.c' control on the Basic Trigger Module PE481D is raised from 'min' towards 'max' a line should be seen growing on the screen in the direction corresponding to diac voltage. When that voltage exceeds a certain limit, current will suddenly start to flow.
(b) Sketch the oscilloscope display.
It should be noted that as the current increases, the displayed characteristic shows the voltage decreasing. That is, a negative-resistance characteristic is being display. The more current flows, the less the diac opposes the current, and so the faster it increases, until a flat enough (non-negative-resistance) part of the characteristic is reached. This is why the current snaps on so very rapidly.
The importance of this is two-fold. First, the rapid rise in trigger current into an SCR guarantees that the timing of conduction will not be upset by tolerances and temperature-dependence of the SCR's gate characteristics. Second, sudden release of stored energy from the capacitor in the trigger circuit means that powerful gate pulses can be delivered from not very powerful control electronics.

(IV) Summary

These experiments have demonstrated simple circuits for triggering a thyristor at a variable phase in the supply cycle. They all use some form of waveform which is positive-going in the relevant time interval, and which reaches a critical level sooner or later, depending on some adjustment to the circuit conditions.

(6)
Light Dimmer

1- Introduction

Experiment exhibits how to control in the duration of lighting of a lamp. Simple control circuit is proposed. The experiment consists of two circuits (power circuit, and control circuit).

2- Tools

Components of power circuit

1-220 v ac supply (50 HZ)
2-Diodes
3-thyristor
4-lamp

Components of control circuit

220/6 v transformer
DC power supplies
741IC (comparator)
Resistances and capacitors

Other Components
Oscilloscope
Board
Wires for connection

3- Procedures

Connect the power circuit as shown in figure (1)

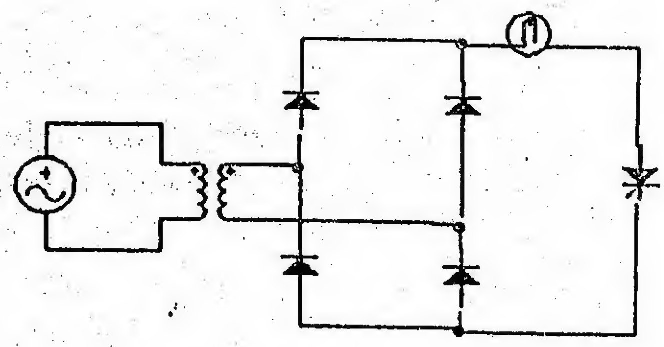


Fig. (1)
Power circuit

The construction of the control circuit (firing) depends on two steps:

Step 1:
To generate a synchronous pulse with 100 HZ by IC741 as shown in figure (2.a).

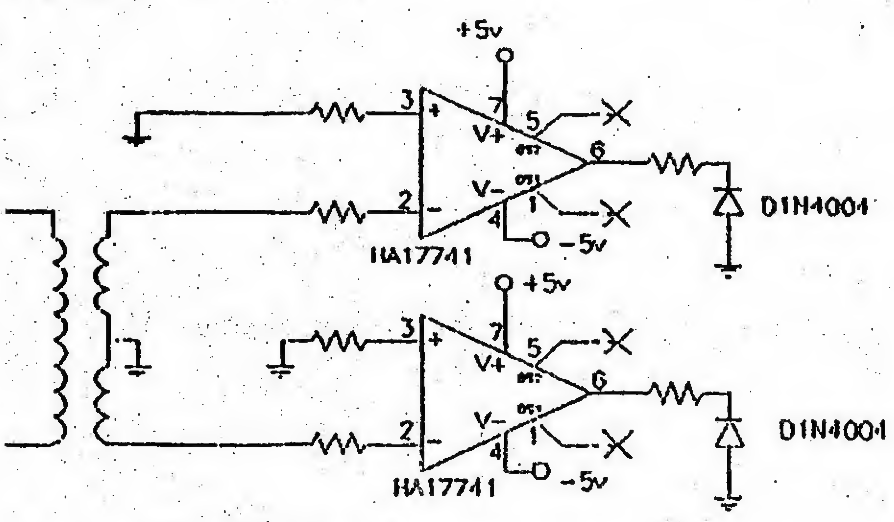


Fig. (2.a) Synchronous pulse generator

Step 2:
Use RC circuit as integrator to obtain triangular waveform.
Compare that wave with DC level whose value depends upon the setting of a variable resistance. As shown in figure (2.b).

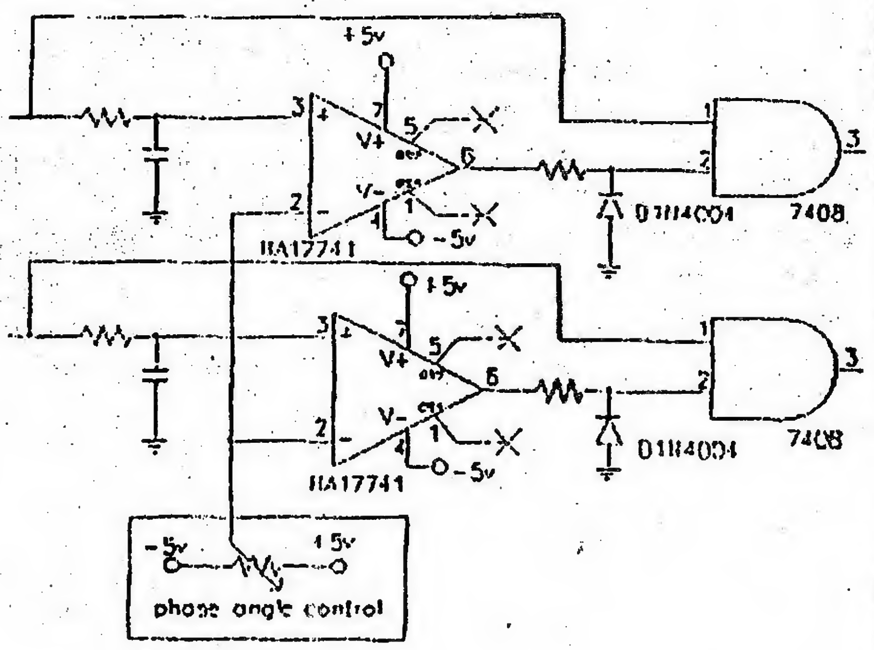


Fig. (2.b) Phase angle control firing circuit

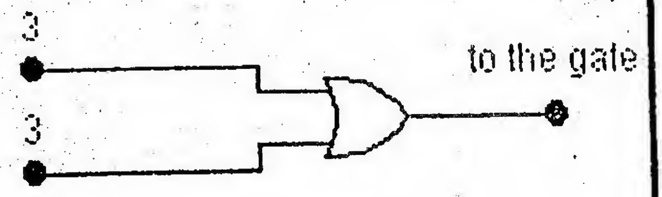


Fig. (3) Or gate (IC7432)

Figure (2) constructs to control in positive and negative half cycles. So the outputs of two AND gates should be add as shown in figure (3)

Questions:

1- S ketch the output of each element of firing circuit?
2- Show how to control in the firing angle?
3- Sketch the load voltage waveform?
4- What is the different between a value of resistance of the lamp before and after lighting?
5- Suppose any other methods to obtain on variable phase angle control circuits?
6- What are the other applications of the previous control circuit?
7- Compare between the percentage of benefits and the costs?
8- Are you benefiting of that experiment? how?

(7)
Armature Voltage Control of d.c. Motors
E4.1 Objective

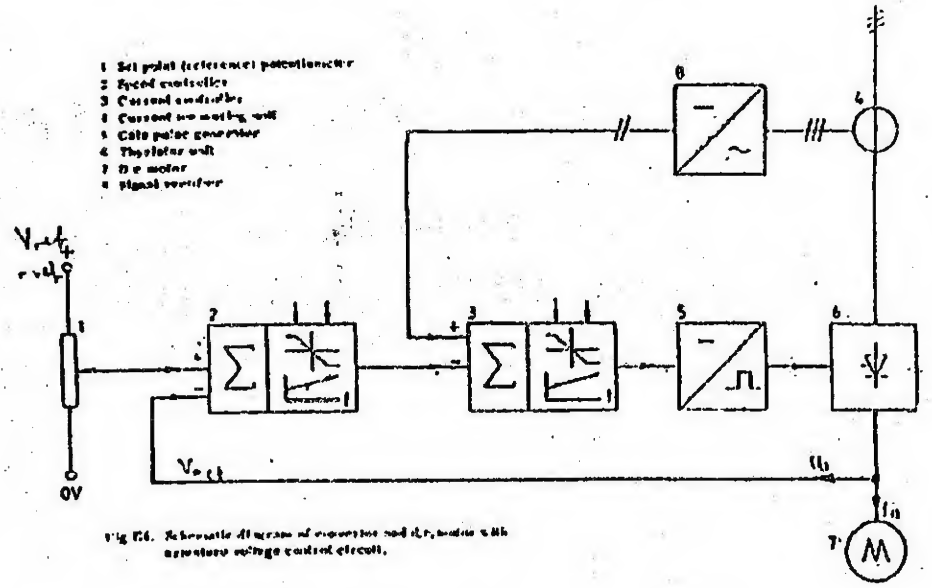
The objective of this experiment is to study armature voltage control of a d.c. motor.

E4.2 Equipment

Art. No. 8000-619Converter	1
Art. No. 8000-056 Transformer	1
Art. No. 8000-417 Variable resistor	2
Art. No. 8000-242 D.c. machine	1
Art. No. 8000-649 Tachogenerator	1
Art. No. 8000-473 Tachometer	1
Art. No. 8000-467 Slip-ring induction motor	1
Art. No. 8000-266 Ammeter	1
Art. No. 8000-267 Voltmeter	1
Art. No. 8000-623 Power supply	1
Art. No. 8000-294 voltmeter	1

E4.3 Theory

Armature voltage control is a simple form of speed control for applications in which a constant speed relatively independent of the load is required. The great advantage of armature voltage control is that it requires no external equipment in the form of a tachogenerator; this makes this type of control system inexpensive.



According to d.c. motor theory

$U_a = (R_a + sL_a).\ I + k.\ \omega_m$

This means that U_a is directly proportional to ω_m

The symbols used in the block diagram in Figure E5 are as follows:

τ_a	= armature time-constant
τ_D	= time-constant for dead time in gate pulse generator
B_{r1}	= gain of voltage controller
B_{r2}	= gain of current controller
$\frac{1+s\tau_{r1}}{s\tau_{r1}}$	= transfer function of voltage controller
$\frac{1+s\tau_{r2}}{s\tau_{r2}}$	= transfer function of current controller

τ_{f1} and τ_{f2} are filter time-constants

SPD is a voltage divider (armature voltage/control voltage)

τ_m = time-constant for run-up time (mechanical inertia)

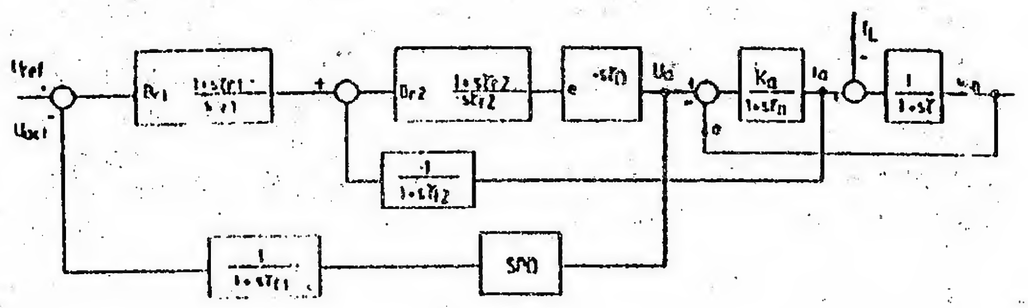


Fig. E3. Schematic diagram of converter and d.c. motor with armature voltage control.

With this control system the converter attempts to maintain the armature voltage U_a at a value corresponding to U_{ref}.

U_a corresponds to the speed ω_m with an error that is directly proportional to the armature current variations $\frac{dI_a}{dt}$.

$$U_a = e + R_a \cdot I_a + L_a \frac{di_a}{dt} \; (e = k \cdot \omega_m)$$

For a reasonably constant load torque T_L equivalent to $\frac{di_a}{dt} \approx 0$, a reference (set point) can be set, and can give good accuracy at constant speed.

E4.4 Method

E4.4.1 Preparatory exercises

The variation of speed and armature current is to be studied, with a constant armature voltage and a variable load resistance.

1. Make the connections according to the circuit diagram at the end of the description of experiment 4.
2. Suitable settings for the converter.

Voltage gain = 2	Voltage time gain = 0.1
Voltage limit 1 = 0.2	Voltage limit 2 = 0.8
Current gain = 6	Current limit 1 = 0.7

3. Switch on the converter.
4. Set the direct current for the braking of the induction motor to 4.5A, by means of the variable transformer in the power supply unit.

5. Reduce the d.c. motor field voltage to about 120V by means of the potentiometer, so that the speed corresponds to 6.
6. The armature voltage feedback is reduced by means of the potentiometer to about 30V and is connected to the input for actual value on the converter. Tune the feedback at the first measurement, so that the speed at complete control is 800 r/m.

E4.4.2 Main exercises

Measurement 1. Adjust the speed with the above setting to 800 r/m. With the load resistance set to position 0, read off the armature voltage and current. Fill in the following table.

R_L Dial pos.	U_a	I_a	n
0			800
8			
16			
24			
32			
40			

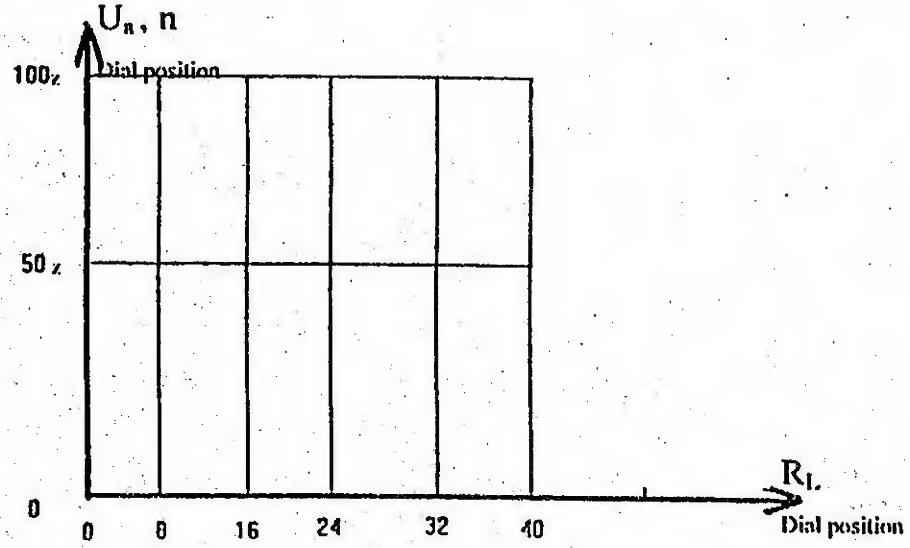
Measurement 2. The degree of control is reduced so that the speed is 600 r/m when R_L has the position 0 on the dial.

R_L Dial pos.	U_a	I_a	n
0			600
8			
16			
24			
32			
40			

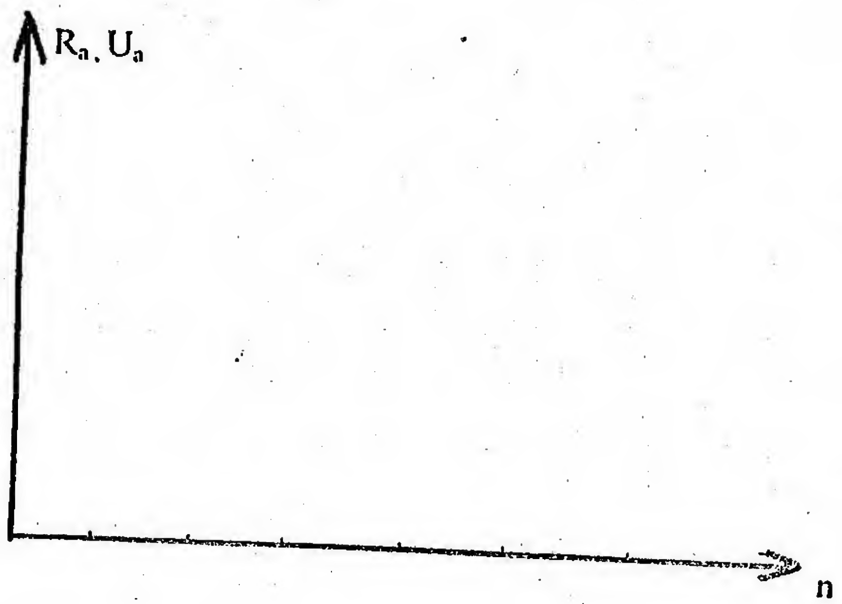
Measurement 3. Reduce the speed to 400 r/m with R_L in position 0.

R_L Dial pos.	U_a	I_a	n
0			400
8			
16			
24			
32			
40			

Plot the armature voltage and speed in "Measurement 2" as functions of the load in the following diagram (2 curves). Explain theoretically why the curves differ.

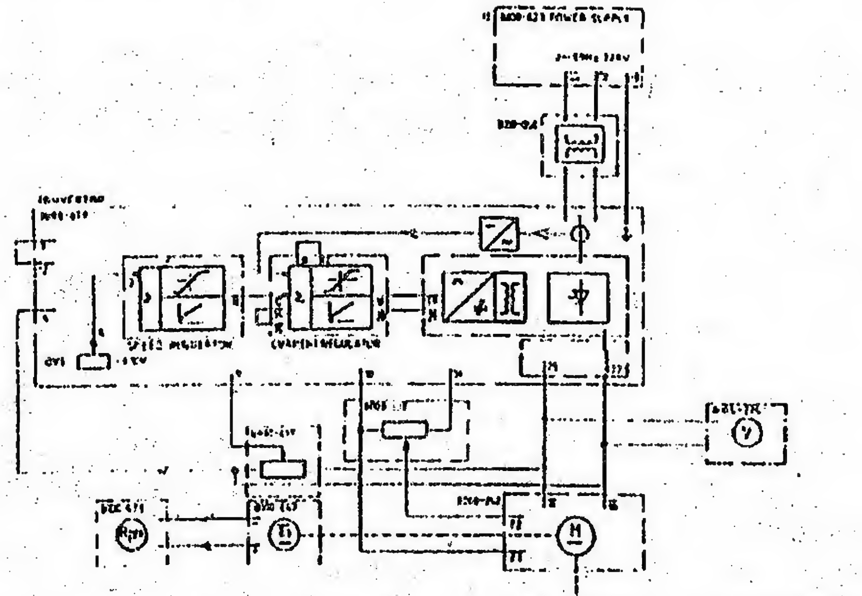


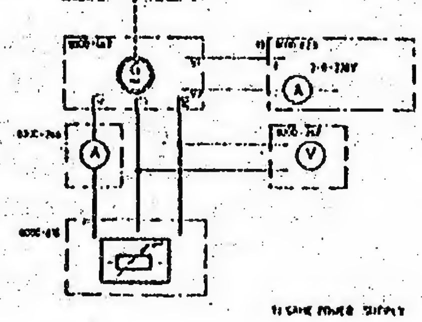
Plot the armature current and voltage as functions of the speed in the following diagram. An estimate of the input and output power can be made from these curves. How?



Comments:

Conclusion:





Connections on the frontpanel

Connection point A	Connection point B
5	2
6	3
5	9
7	10
14	15
18	19
20	21

(IV)

Power Systems Experiments

(1)
Short Transmission Line- Performance Chart

I- Object

To perform load tests o a short transmission line and to draw its receiving end performance chart with special reference to the line's static power limit.

II- Pre-Lab:

How can the power transmitted by the line be increased when Vs = Vr? What are the limiting factors?

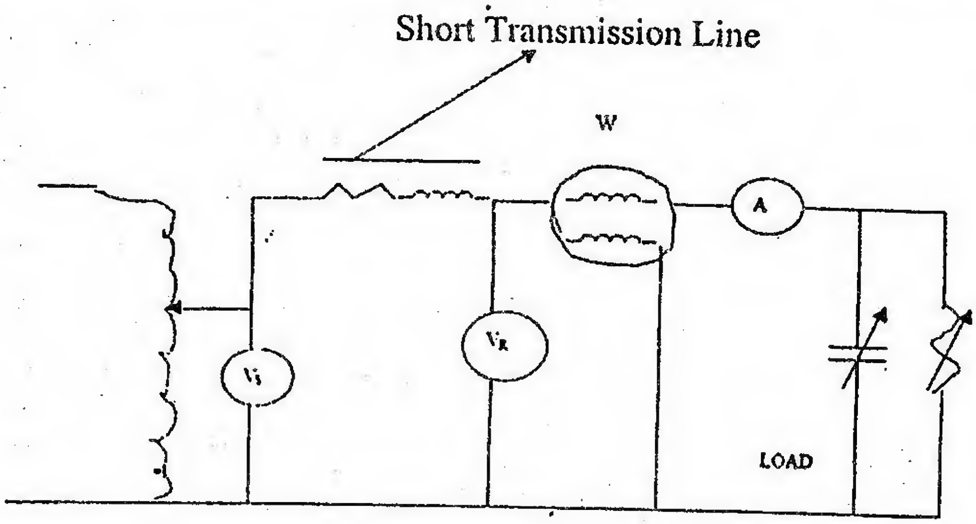
III- Lab-Task:

1. Carry out a short circuit test on the short transmission line (represented by the reactor) to find its impedance and angle. Select the most suitable instrument settings.
2. Use the circuit shown below for the load tests
3. Carry out a load test by increasing the value of capacitance until the power passes through a maximum. Use the resistance bank to maintain Vs = Vr. Steps of 5 MF are suggested. Prepare a table of values to record all quantities. The table should have space for reactive volt-amperes,
4. Take the capacitor out of circuit leaving a purely resistive load. Increase the current from zero to the maximum possible with the variac, maintaining Vr = 200 V. Record voltage, current and power.

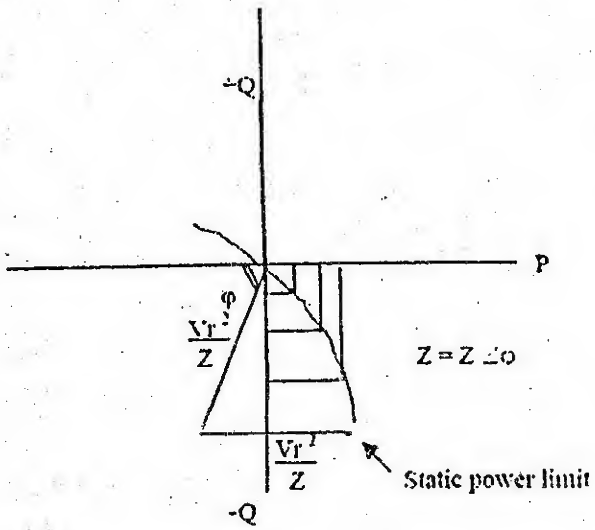
IV- Lab-Report:

1. Calculate the magnitude of the line impedance and the impedance angle.
2. Calculate the reactive volt-amperes for the load test to complete the table of values.
3. Construct scales for current and volt-amperes based on a voltage scale of 1cm = 20 V, an prepare the receiving end performance chart
4. Plot the value from the first load test using the value for active & reactive power.
5. Plot the points from the second load test using the values of Vs and power.
6. On the chart draw the locus of Vs = Vr, the static power limit & the stability limit.
7. Compare the measured value from each test with the corresponding theoretical value.

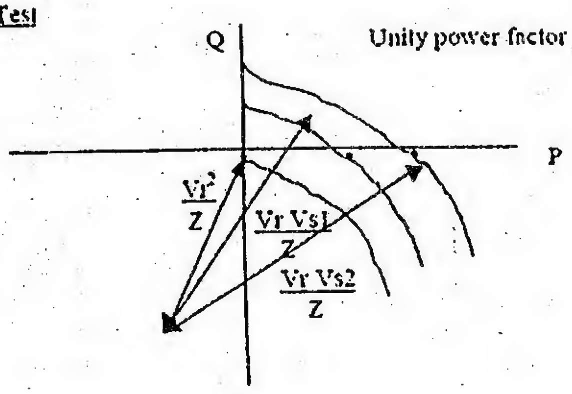
8. If Vs is limited to Vr + or - 15%, what is the maximum powr carried by the line with a resistive load?



Experimental setup



Second Load Test



(2)
Balancing of Unbalanced Three-phase Loads

Unbalanced load cause several consequences in power systems. They create negative sequence currents, higher losses, unbalanced voltage drops and unequal voltage magnitudes at load terminals pulsating torques in machines, ripples in rectifier circuits, malfunction of control and protection systems based on balanced conditions. Unbalance may lead to unability of induction motors to start and to voltage instability and/or synchronous instabilities. Harmonics can be created and harmonic resonamces may triggered which can disturb the system, saturate in transformers are the main cause of such harmonics. Heavy losses in neutral wires occur, besides initial capital costs must be expended to increase the cross-sections of such conductors.

(i) Balancing of Resistive Load:

Having a resistive load of conductance G_l between (a, b): it was found in ref. (1) that this load can be completely balanced by addition of ($-jG_l/\sqrt{3}$) between (b, c) and ($+jG_l/\sqrt{3}$) between (a, c), i.e a reactor should be connected between (b, c) and a capacitor is to be connected between (a, c), with the above reactances which are ($-G_l/\sqrt{3}$) and ($+G_l/\sqrt{3}$). The currents in the three-phases will be equal in magnitudes and they are displaced by 120° from each other. Noting that these currents were severely unbalanced. Ic was equal to zero and $I_a = I_b$. Now $[I_a] = [I_b] = [I_c] = [I]$ and they have 120 displacement from each other. They will be inphase with the corresponding voltages.

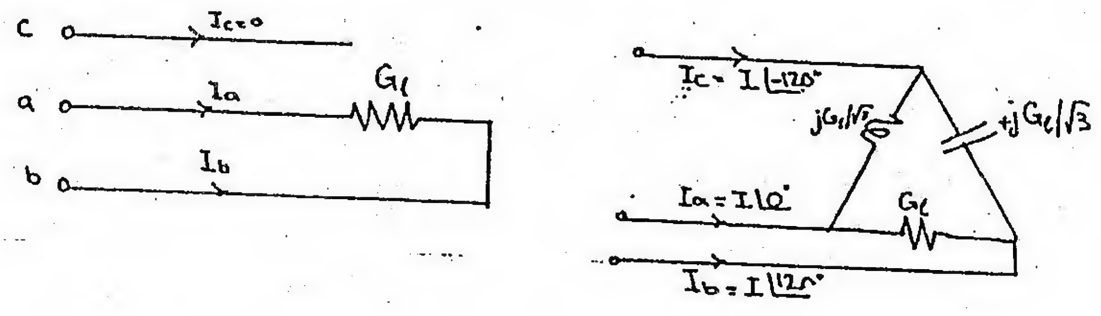


Fig. 1 Unbalanced & balanced case

(ii) Balancing of an Impedance Load:

The load impedance will be $Z_l = R_l + jX_l$, and its admittance will be $Y_l = G_l + jB_l$.

If the load admittance is compensated by admittance ($-jB_l$). Then the problem will turn to be a problem of an resistive load of conductance G_l. this will be balanced by two reactive admittance's ($-jG_l\sqrt{3}$) and ($+jG_l\sqrt{3}$) connected to the third opened line end from the two terminals of the unbalanced load at a, b as shown in Fig. 3.

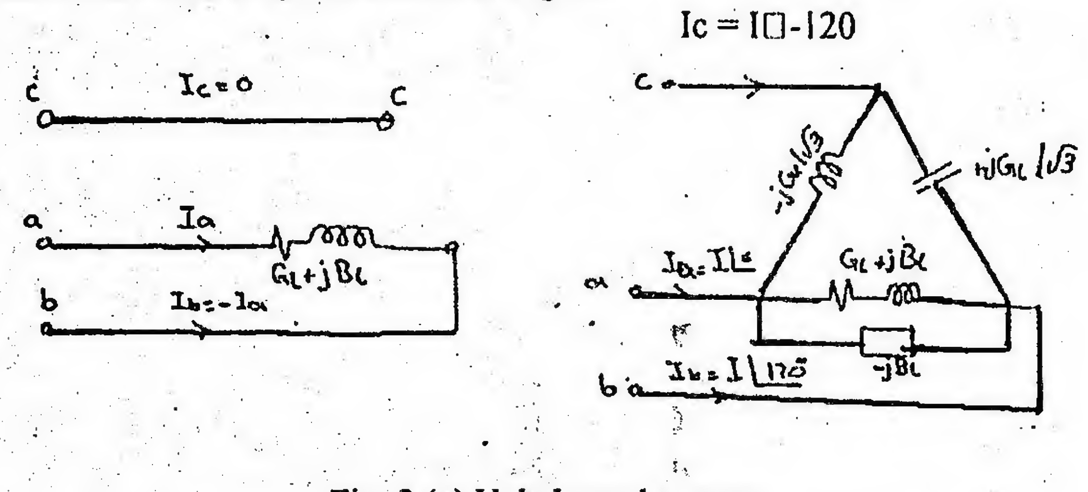


Fig. 2 (a) Unbalanced system
(b) Balanced system

Noting that the magnitude of [I] is generally less than I_a, I_b in the unbalance conditions

(iii) Balancing of 3-phase unbalanced Load:

Assuming each of these loads connected between two lines (a, b), (b, c) and (c, a). Their admittances are $Y_l^{ab} = G_l^{ab} + jB_l^{ab}$, $Y1_l^{bc} = G_l^{bc} = G_l^{bc} + jB_l^{bc}$ and $Y_l^{ca} = G_l^{ca} + jB_l^{ca}$. Applying the above concept and theory for each load alone, each one must be balanced by a shunt susceptance – JB1 and two susceptances with the third node of value ($+jG_l/\sqrt{3}$), ($-jG_l/\sqrt{3}$). Aggregation of the required susceptance will give the total required susceptances between the lines in delta form as:

$B_c^{ab} = -B_l^{ab} + j(G_l^{ca} - G_l^{bc})/\sqrt{3}$

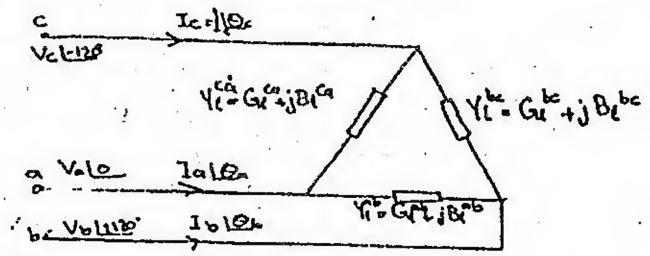
$B_c^{bc} = -B_l^{bc} + j(G_l^{ab} - G_l^{ca})/\sqrt{3}$

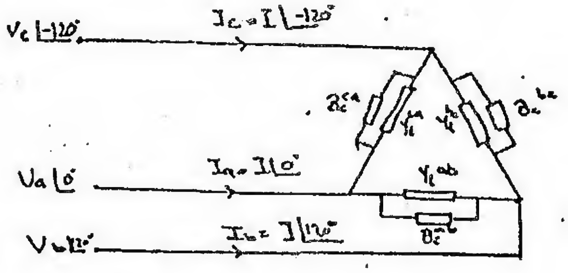
$B_c^{ca} = -B_l^{ca} + j(G_l^{bc} - G_l^{ab})/\sqrt{3}$

Connection of such susceptance in shunt with the load adjust their current magnitudes to a certain equal value and will modify their phase to

be inphase with each respective voltage phase, i.e. will improve their power factor unity.

(a) Unbalanced 3-phase load





(b) Balanced 3-phase load

Steps of the test:

1. Having a certain resistive load R Get G and connect it between phase a, b measure I_a, I_b and I_c and their phases

2. Connect a reactive susceptance $-jG_l/\sqrt{3}$ (inductance) between lines (a, c) and another $+jG_l/\sqrt{3}$ (capacitance) between (b, c). Measure the three currents and their phases. Record your results in the following table:

(a, b) load resistance = ohm, $G_l/\sqrt{3}$
(a, b) load conductance

Phase #	Before Balancing				After Balancing				lines losses B.B.	lines losses A.B.
	Line voltage		Line currents		Line voltage		Line currents			
Phase A										

Phase B										
Phase C										

BB: before balancing AB = After balancing

Line losses calculated on base of one ohm resistance for the feeder to the load.

3. Repeat steps 1, 2 for other resisting loads between (b, c) and (c, a).

4. Use an impedance load between a, b
$Y_1^{ab} = G_1^{ab} + jB_1^{ab}$
& connect (jB_1^{ab}) in shunt with the load together with ($-jG_1^{ab}/\sqrt{3}$) and ($+G_1^{ab}/\sqrt{3}$) between the other nodes and the third node "C"

5. Measure the currents and their phase angles together with the line voltages and their phase angles before and after connection of $-jB_1^{ab}$, $-jG_1^{ab}/\sqrt{3}$ and $+jG_1^{ab}/\sqrt{3}$, in their appropriate positions and record ypur results in the following table.

$Y_1^{ab} = G_1^{ab} + jB_1^{ab} = +$ mho, $G_1/\sqrt{3}$

	Before Balancing				After Balancing				lines losses B.B.	Lines Losses A.B.
	Line voltage		Line currents		Line voltage		Line currents			
Phase A										
Phase B										
Phase C										

6. Use a three-phase unbalanced load with
$Y_1^{ab} = G_1^{ab} + jB_1^{ab}$
$Y_1^{bc} = G_1^{bc} + jB_1^{bc}$
$Y_1^{ca} = G_1^{ca} + jB_1^{ca}$

And connect the appropriate:

B_c^{ab}, B_c^{bc}, B_c^{ca}.

(3)
Benefits of loads power factor correction

Loads power factor is defined as the percent of its useful (active) power to its apparent (VA) power. They should be kept within certain (Not less than 0.9 in Egypt, Not less than 0.86 in USA and Europe). Improvement of power factors, to values more than those limits, result in more technical and economical advantages and to raise of power quality.

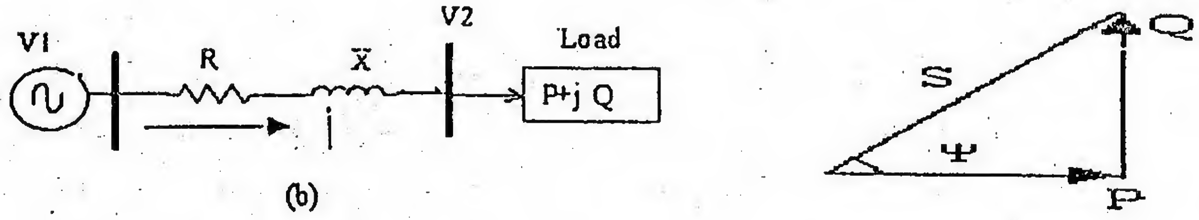
Aim of Tests:

To detect the benefits of power factor improvements experimentally and to verify them theoretically through simple calculations.

Definition:

Regarding load power triangle fig.1, the load power factor is defined by:

Power factor ($\cos\varphi$) $= \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}}$



(b)

Fig.1 (a) Load Power triangle

(b) Load Fed from two nodes networks

From which:

$Q = P \tan\varphi$

Measure the voltage, currents and their phases and losses before using compensator susceptances and after using these susceptances and record your results in the following table

$Y_1^{ab} = Y_1^{bc} + Y_1^{ca}$
$B_1^{ab} = B_1^{bc} + B_1^{ca}$

	Before Balancing				After Balancing				lines losses B.B.	Lines losses A.B.
	Line voltage		Line currents		Line voltage		Line currents			
Phase A										
Phase B										
Phase C										

- Losses are calculated on one ohm feeder resistance for each of the 3-lines.

7. Comment on your results

8. Try (if possible) to use variable loads and to get variable B_c^{ab}, B_c^{bc}, B_c^{ca} and repeat (3-5) for each load.

$$S = \sqrt{P^2 + Q^2}$$

$$P = \sqrt{S^2 - Q^2}$$

$$I = \sqrt{\left(\frac{P}{V}\right)^2 + \left(\frac{Q}{V}\right)^2}$$

Meaning of power factor Improvement:
As the load power "P" should be kept constant by load requirement, the load power factor is dependent on the load needs of reactive power "Q". transit of such reactive power on feeding network result in:

(a) Heavy line currents as:

$$I_1 = \sqrt{\left(\frac{P}{V}\right)^2 + \left(\frac{Q}{V}\right)^2}$$

(b) These heavy line currents are accomplished by heavy losses as:

$$P_{Loss} = I_1^2 R = \left(\frac{P}{V}\right)^2 R + \left(\frac{Q}{V}\right)^2 R$$

(c) and in need for large lines cross section "a" as:

$$a_1 = \frac{I_1}{i}$$

i is the current density in (Amp/mm^2)

(d) More line voltage drops (or lower voltage levels) as:

$$|\Delta V| = |V_1| - |V_2| = \frac{XQ + RP}{|V_2|}$$

less $|\Delta V|$ means more $|V_2|$, assuming $|V_1|$ is kept constant.

(e) Less power available from generators, transformers, lines and busbars as:

$$P = \sqrt{S^2 - Q^2}$$

More load Q means less P available for consumers.

Factor correction capacitors
Ideal power factor is unity, which means Q on lines should be zero. This can be done by connecting capacitors in shunt with the load. The load need of the reactive power is then totally fed locally from that capacitor. Normally unity load power factor is not favorable from economic point of view. So a shunt capacitor is required to feed the load by Q_c and the line reactive power become then Q_2 instead of Q_1, fig.3. The capacitor reactive power is

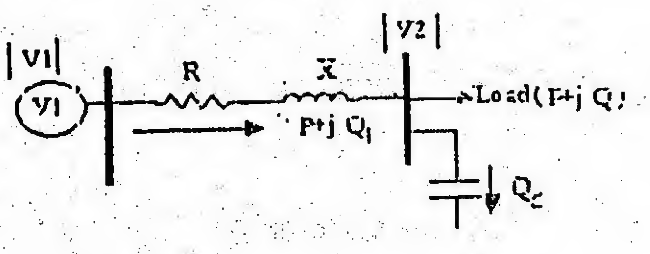


Fig. 2

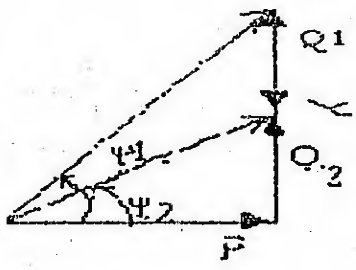


Fig. 3

Fig. (2) Power system loaded by a load P,Q_1 and compensated by Q_c
Fig. (3) Power triangle

defined by:
$Q_c = P(\tan\varphi_1 - \tan\varphi_2) = P(K)$
K is a numerical factor obtained from tables.

Benefits of load power factor correction:
From the above discussion, load power factor correction means less reactive power transit on lines (Q_2 instead of Q_1), ($Q_2 = Q - Q_c$)
Therefore, load power factor correction result in the following benefits:

(1) Less transit currents on lines, transformers, circuit breaker, buses and generators, as I_2 after Pf correction is given by:

$$I_2 = \sqrt{\left(\frac{P}{V}\right)^2 + \left(\frac{Q_2}{V}\right)^2}$$

(2) Less losses as:

$$P_{Loss\,2} = I_2^2 R = \left(\frac{P}{V}\right)^2 R + \left(\frac{Q_2}{V}\right)^2 R$$

(3) Less lines cross sections (a2), given by

$$a_2 = \frac{I_2}{I_1} a_1$$

Noting that I_2 is less than I_1

(4) Less lines voltage drops (or higher voltage levels) as:

$$\Delta V = |V_1| - |V_2'| = \frac{XQ_2 + RP}{|V_2|}$$

Noting that Q_2 is less than Q_1, $|V_2'|$ will be more than $|V_2|$

(5) More available power for other consumers as:

$P = \sqrt{S^2 - Q_2^2}$, $(Q_2 < Q_1)$

Ideally, we can have $P = S$. if $Q_2 = 0$ or at unity load power factor.

Experiment connection diagram:

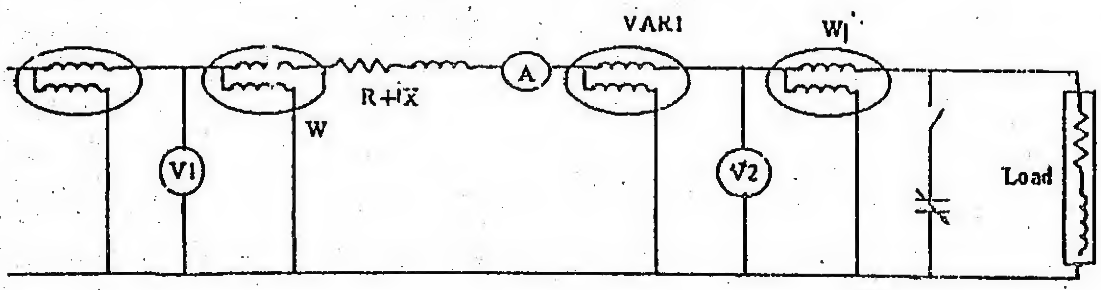


Fig.4 Connection diagram

Fig. 4 shows the experiment connection diagram ratings should be defined for instruments according to load currents and powers. Special attention should be paid to VAR meters connections.

A single-phase load is fed through short line of R + jx, connect wattmeters and VAR meters at the load terminals and at the supply terminals (W_1, VAR1), (W_1, VAR2) together with volt meters V_1, V_2 and an ammeter "A".

Tests:

(1) With the load at its normal condition, measure its initial power P, reactive power Q, voltages (V_1, V_2), current I_1 and power factor. Find line losses ($P_2 - P_1$).

(2) Introduce shunt capacitor with different capacitor and record the following

(a) current reduction recent:

Pf1										
Pf2										
I_1										
I_2										
% reduction I_1- $I_2/I^1\times100$										

(b) Lines losses reduction:

Pf1										
Pf2										
Ploss1										
Ploss2										
Persentg ploss1 - ploss2/ploss1										

(c) Lines cross section reaction:

Pf1										
Pf2										
a1										
a2										
(a1-a2)/a1 % reduction										

(d) Percentage increase in load voltage:

Pf1										
Pf2										
V_1 before										
V_2 after										
% $[(V_2' - V_2)/V_2]\times 100$										

(e) Available load power for new consumers:

Pf1										
Pf2										
Ploss1										
Ploss2										
% increase (Psource1- Psource2) / Psource1 ×100										

Comments:

- Plot the value of the capacitor reactive power Q_c to improve the load power factor from actual power factor Pf_1 up to unity. Plot Q_c against the power factor. Prove the power factor of (0.92-0.93) is economically favorable. More power factors are not acceptable.

Penalty and Bonus:

In Egypt, power less than 0.4 are not allowed. Load power factors from 0.4 to 0.9 will have certain penality. No penality for power factors from 0.9 to 0.95. Ponous is given for load power factor than 0.95.

Comment on your results: